INDUSTRIAL EVOLUTION AND NATIONAL INSTITUTIONAL ADVANTAGE: A COMPARATIVE ANALYSIS OF THE PHOTOVOLTAIC INDUSTRY IN GERMANY, CHINA AND SOUTH KOREA

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ABSTRACT

A number of alternative economic and economic geography theories have been developed to account for the divergence of national political economy and industrial dynamics. These include the varieties of capitalism, developmental state, neo-Schumpeterian innovation, and Gerschenkronian catching-up theories. In this thesis I shall argue that in these theories a core and often shared concept of 'institutional advantage' plays a central role in explaining different economic performances across nations.

This concept is elaborated as a means of examining the causal relationships between institutional advantages and four necessary functions (market creation, capital mobilisation, process innovation and cost reduction) in the development of the photovoltaic (PV) industry of Germany, China, and South Korea. The development of these industries is examined in detail on the basis of empirical evidence in the form of archival and interview based data.

Two main conclusions are reached. Firstly, domestic market creation is not a generally necessary condition for the development of a local PV industry at a national level. China's PV industry grew fast without a sufficient domestic market unlike in Germany. However, domestic market creation is important, because the domestic PV industry, national support policy and the domestic market are interrelated. Secondly, capital mobilisation is a core function in establishing the PV industry. In the 2000s, Korea failed to establish its local PV industry despite an institutional advantage in creating domestic markets, mainly due to the fact that it had an institutional disadvantage in mobilising capital. However, Germany and China succeeded in mobilising capital in their PV sectors, governments playing a decisive role in facilitating the raising of funds in both cases.

This research contributes to a better understanding of the nature of industrial dynamics in the context of institutional configurations of a national political economy, broadening the usage of 'institutional advantage' by applying this concept to comparative analysis on the national PV trajectories. Moreover, from the perspective of the social system, four necessary functions for the PV industry have been proposed and investigated.

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Statement

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:

Date:

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List of Abbreviations

AEDPA	Alternative Energy Development Promotion Act (Korea)
AG	*Aktiengesellschaft* (Public Limited Company)
ASEAN	Association of Southeast Asian Nations
a-Si	amorphous Silicon
BIPV	Building Integrated PV
BIS	Bank for International Settlements
BMFT	*Bundesministerium für Forschung und Technologie* (Federal Ministry for Research and Technology)
BMU	*Budesministerium für Umwelt, Naturschutz und Reaktorsicherheit* (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMWA	*Budesminsterium für Wirtschaft und Arbeit* (Federal Ministry for Economy and Labour)
BSW	*Budesverband Solarwirtschaft* (German Solar Industry Association)
CCP	Chinese Communist Party
CdTe	Cadmium Telluride
CDU	Christian Democratic Union of Germany
CE	Chief Engineer
CEC	Commission of the European Community
CEO	Chief Executive Officer
CIGS	Copper Indium Gallium Selenide
CIS	Copper Indium Selenide
CME	Coordinated Market Economy
COO	Chief Operating Officer
CRED	Centre for Renewable Energy Development (China)
CREDP	China Renewable Energy Development Project
c-Si	crystalline Silicon
CSU	Christian Social Union
CTI	Committee of Trade and Industry, National Assembly in Korea
CTO	Chief Technology Officer
DM	Deutsch Mark
EBIT	Earning Before Interest and Tax

ECJRC	European Commission Joint Research Centre
ECU	European Currency Unit
EEG	*Erneuerbare Energien Gesetz* (Renewable Energy Source Law)
EPB	Economic Planning Board (Korea)
EPIA	European Photovoltaic Industry Association
ESRC	Economic and Social Research Council (UK)
FDI	Foreign Direct Investment
FIAT	Field Information Agency, Technical (Germany)
FIT	Feed-in Tariff
FRG	Federal Republic of Germany
FSC	Financial Supervisory Commission (Korea)
FTC	Fair Trade Commission (Korea)
FYP	Five Year Plan
GDP	Gross Domestic Production
GDR	German Democratic Republic
GKU	Green Korea United
GLCs	Government-linked Companies
GmbH	*Gesellschaft mit beschränkter Haftung* (Company with limited liability)
GNP	Gross National Production
HHI	Hyundai Heavy Industries (Korea)
HRS	Household Responsibility System (China)
HS	Harmonised Commodity Descripition and Coding System
HSK	Harmonised System of Korea
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ILC	Industry Life Cycle
IPO	Initial Public Offering
JVs	Joint Ventures
KEEI	Korea Energy Economics Institute
KEMC	Korea Energy Management Corporation
KEPCO	Korea Electric Power Corporation
KERRI	Korea Energy and Resources Research Institute
KFEM	Korean Federation for Environmental Movement

KIER	Korea Institute of Energy Research
KIIP	Korea Institute for Industrial Policy
KIST	Korea Institute of Science and Technology
KITA	Korea International Trade Association
KMPA	Korea Maritime and Port Administration
KNEN	Korean NGO's Energy Network
KNREA	Korean New and Renewable Energy Association
KNREC	Korea New and Renewable Energy Centre
KW	Korean Won
kWp	kilo watt peak
LME	Liberal Market Economy
M&A	Merger and Acquisition
MKE	Ministry of Knowledge Economy (Korea)
MNCs	Multi National Companies
MOCIE	Ministry of Commerce, Industry and Energy (Korea)
MOER	Ministry of Energy and Resources (Korea)
MOFE	Ministry of Finance and Economy (Korea)
MOPB	Ministry of Planning and Budget (Korea)
MOST	Ministry of Science and Technology (China)
MOTIE	Ministry of Trade, Industry and Energy (Korea)
MWh	Mega watt hour
MWp	Mega watt peak
NBSC	National Bureau of Statistics of China
NDRC	National Development and Reform Commission (China)
NICs	Newly Industrialising Countries
NIEs	Newly Industrialised Economies
NSI	National Systems of Innovation
NYSE	New York Stock Exchange
ODI	Outward Direct Investment
ODM	Own-designed and Manufacture
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacture
OIM	Operating Income Margin
P-N	Positive and Negative

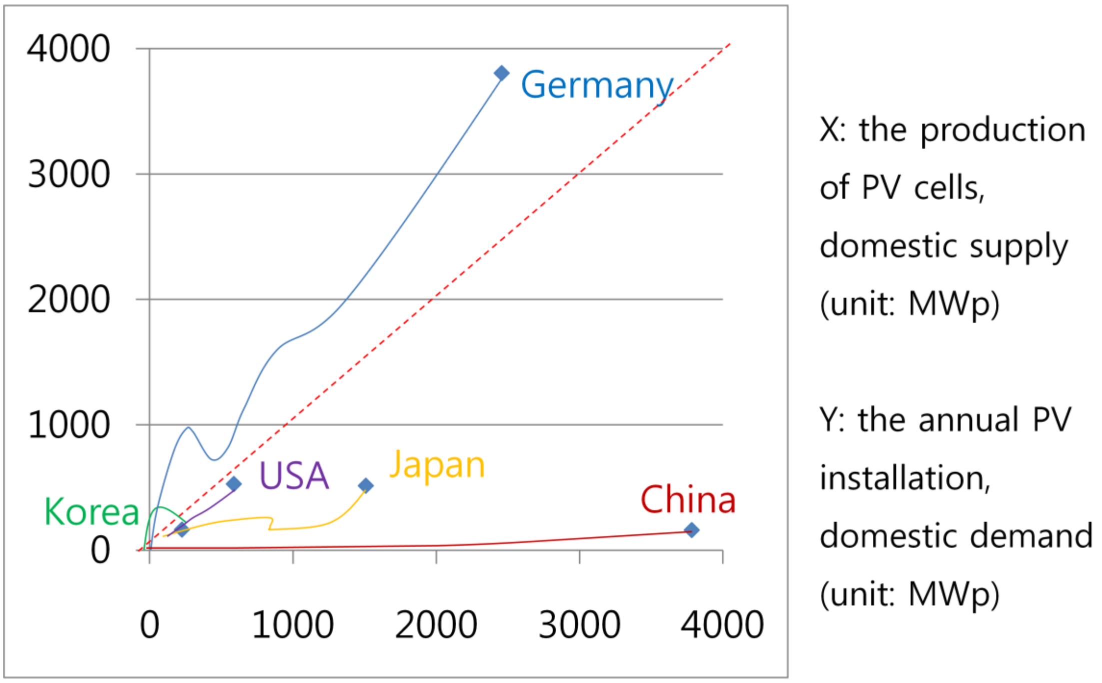
PRC	People's Republic of China
PV	Photovoltaic
R&D	Research and Development
RDD	Research, Development and Demonstration
RMB	*Renminbi* (Chinese Yuan)
RPS	Renewable Portfolio Standard
SE	Samsung Electronics (Korea)
SEZs	Special Economic Zones (China)
SMEs	Small Medium-sized Enterprises
SNEC	Shanghai New International Expo Centre
SOEs	State-owned Enterprises
SPC	State Planning Commission (China)
SPD	*Sozialdemokratische Partei Deutschlands* (Social Democratic Party of Germany)
TFP	Total Factor Productivity
TNCs	Trans National Companies
TÜ V	*Technischer Ü berwachungsverein* (German safety monitoring agency)
TVEs	Township and Village Enterprises
UNFCCC	United Nations Framework Convention on Climate Change
UNSW	University of New South Wales in Australia
USD	United States Dollar
USSR	Union of Soviet Socialist Republics
VAT	Value Added Tax
VDEW	*Verband der Elektrizitätswritschaft* (German Electricity Association)
VDMA	*Verband Deutscher Maschinen und Anlagenbau* (German Engineering Federation)
VoC	Varieties of Capitalism
VP	Vice President
Wp	watt peak
WTO	World Trade Organization
µm	micron meter (one millionth of a meter)

CHAPTER I INTRODUCTION

1. RESEARCH BACKGROUND

It is argued that deploying renewable energy is one of the best ways to cope with climate change and to establish a sustainable energy system (IEA, 2008). In terms of potential, photovoltaic (PV) electricity is one of the most promising alternatives to the current fossil fuel-dominant energy system (De Vries *et al.*, 2007; Resch *et al.*, 2008). In order to deploy PV electricity, it is essential to develop a PV industry. Figure I-1 shows the national PV growth trajectories in five representative countries[1] in the 2000s.

Figure I-1 National PV growth trajectories in the five countries between 2001 and 2009



Source: BSW (2009; 2010), EPIA (2009; 2010), KNREC (2009), Roney (2010)

Surprisingly, there have been significant differences across the five countries. In some countries, an increase in domestic demand seems to have led to an increase in domestic supply, whilst the production of solar cells has increased without sufficient domestic demand in other countries. Why did these differences occur? And how can they be

[1] Also, Spain, Italy, and Taiwan can be included in the representative countries. However, access to full data of these countries is limited for me, thus I have excluded them in this analysis.

explained? These questions are the starting point of this research.

Theoretically, these differences seem to be explained by the concept of comparative advantage held by neoclassical economists. However, this concept cannot explain sufficiently the nature of industrial dynamics in the long-term (Lin and Chang, 2009). Rather, it seems to be more relevant to regard these differences as a sectoral example of diversity within capitalism. With regard to divergent capitalisms, there have been many attempts to analyse and categorise a range of market economies within comparative capitalism theories (Hollingsworth *et al*., 1994; Streeck, 1997; Whitley, 1999; Dore, 2000; Hall and Soskice, 2001; Weiss, 2003; Morgan, 2005). The varieties of capitalism (VoC) approach seems to offer some of the most useful literature for solving the questions above. This is because it provides us with the concept of 'comparative institutional advantage' (Hall and Soskice, 2001, p.37) which can be applied to analyse firms' different systematic activities and performances in the context of institutional arrangements[2].

Moreover, it is necessary to synthesise this national level approach with an industrial level perspective, because the focal point of this research is the evolution of *an industry* in the context of a national political economy. Thus, these differences also need to be investigated using an industrial dynamics approach such as an industry life cycle (ILC) theory.

So far not much research has been carried out with a view to bridge institutional configurations of national political economies and industrial dynamics using the concept of institutional advantage. Thus, I believe that this research can contribute to broadening the concept of 'institutional advantage' and understanding comprehensively the nature of 'industrial dynamics'.

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[2] The 'ecological modernisation' approach has attempted to integrate economic development and environmental protection (Mol and Sonnenfeld, 2000). Furthermore, Gibbs (2006) attempts to link the ecological modernisation and regulationist approaches. On the whole, I fully agree with the point that economic geographers should pay more attention to environmental debates (Gibbs, 2006), but this thesis focuses more on the comparative analysis of national PV industrial dynamics from the perspective of the varieties of capitalism approach rather than from the perspective of 'ecological modernisation' or Gibb's suggestion.

2. RESEARCH OBJECTIVES

The aim of this research is to reveal and understand the causal relationships between institutional configurations and various national PV trajectories. In order to achieve this aim, my overarching research question is as follows:

What are the main factors underlying the differences between national PV growth trajectories?

More specifically, two sub-questions have been introduced to devise a conceptual framework.

(1) If the concept of 'institutional advantage' is relevant in analysing these differences, how then can the concept explain them?
(2) What is a linking concept between national institutional configurations and PV industrial dynamics?

In order to clarify how institutional advantages influence the emergence and evolution of the PV industry, I have assumed that four necessary functions (*market formation; capital mobilisation; process innovation; and cost reduction*) facilitate the development of the PV industry. These four necessary functions are the intermediary concept between institutional advantage and the development of the PV industry. This assumption is based on Van de Ven and Garud's (2000) three functional subsystems for an emergence of an industry and Jacobsson and Bergek's (2004) four features of the formative period of renewable energy industries. I will discuss in detail later (II.3.2.4 p. 35, III.3.3 pp. 47-48, and III.4.3 pp. 55-56).

Thus, within the context of the above conceptual framework this study adopts the following hypothesis:

One country's PV industry is able to grow faster than that of another country, because it has institutional advantages which are relevant to the four functions.

Therefore, testing this hypothesis and explaining the causal relationship between institutional advantages and the four functions are the main objectives of this research.

3. RESEARCH METHODOLOGY

This section summarises the methods used in this research. I will explain the methods in detail in chapter IV.

In seeking to answer these research questions, firstly, I chose three cases (Germany, China and South Korea) in accordance with the ‘polar type’ selection (Eisenhardt, 1989, p. 537). As shown in Figure I-1, Germany’s PV production increased alongside the growth of the domestic PV market, whilst China’s PV production grew without sufficient domestic PV demand. In South Korea (henceforth Korea), despite an initial strong growth in domestic PV demand, the PV industry was not established. Thus, in the main chapters (V, VI, VII and VIII) I will explain these differences using, in turn, a within-case analysis and a cross-case analysis.

Secondly, data were collected by both archival research and interviews in order to understand and explain the three cases. These two data sources were cross-checked because they had a complementary relationship. The most challenging aspect of the research was the field work. In the Korean case, data collecting was less difficult because I was able to take advantage of my connections with government officials and a common language. However, this was not the case in Germany and China. In Germany, major PV companies such as Q-Cells were very reluctant to meet researchers[3]. However, mainly due to the support from the Korean-German Chamber and the UK ESRC (the Economic and Social Research Council) project, I was able to successfully carry out my fieldwork. In China, language was a problem in meeting with some interviewees and I was therefore accompanied by an interpreter. Finally, I was able to conduct 48 interviews (Korea: 25, China: 15, and Germany: 8) despite time and budget constraints.

Due to these detailed case studies, I believe this research can contribute to empirical knowledge about China and Korea’s PV industries because very little previous research has been carried out concerning the PV sector in these two countries.

[3] However, major PV companies published annual reports, because these companies were listed on the stock market. Thus, these annual reports compensated for the difficulty of interviewing in Germany.

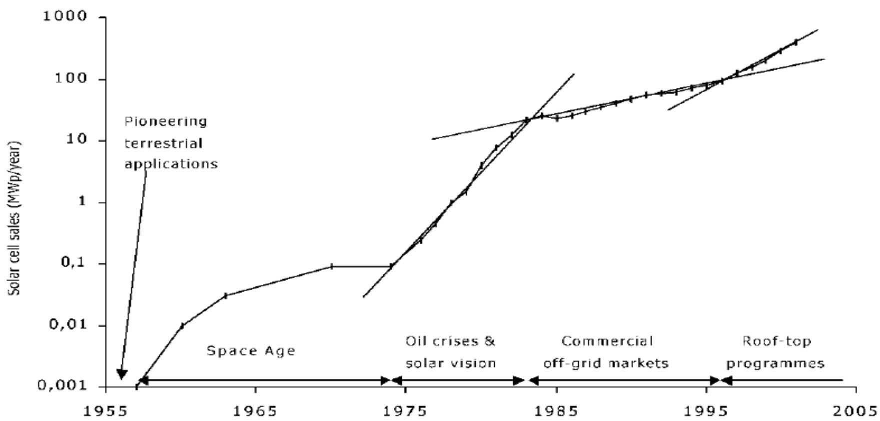
4. EMPIRICAL CONTEXT

Before proceeding further, it is necessary to start by outlining a brief history and the industrial structure of the PV sector. This is because it is easier to understand the industrial dynamics of the PV sector, when you know the historical background and the particular structure of the PV industry.

4.1 Brief History of the PV Sector

The discovery of the photovoltaic effect opened the PV sector in terms of scientific knowledge in 1839 (Wolf, 1972). After that, early PV cells were invented in various designs, as I will describe in detail later (V.3.1.1). In 1954, the invention of the first modern silicon solar cells began the first phase of solar cells diffusion, as shown in Figure I-2. From 1958, the first commercial PV market started with the space satellite market (the second phase) (Wolf, 1972). After the oil crisis in the 1970s, many PV experiments were carried out in order to develop alternative energy sources (the third phase). In the 1980s, off-grid PV markets for special use such as PV lamps for railroad stations and PV systems for lighthouses gradually increased (the fourth phase). Finally, from the late 1990s, on-grid PV markets started (the fifth phase). These five phases of solar cell markets are illustrated in Figure I-2.

Figure I-2 Five phases of solar cells diffusion



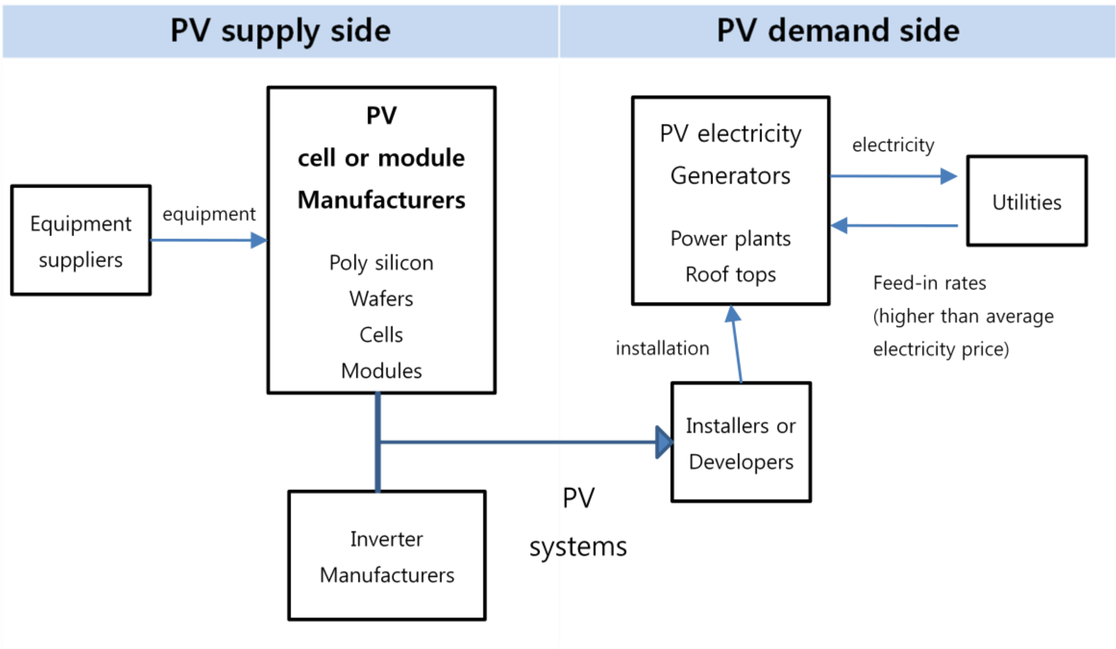
Source: Jacobsson *et al.*, 2004, p. 8

The five phases: (1) Pioneering terrestrial applications; (2) Space Age; (3) Oil crises & solar vision; (4) Commercial off-grid markets; and (5) Roof-top programmes

4.2 Industrial Structure of the PV Sector

The main actors[4] in the PV sector are illustrated in Figure I-3. Seen as a whole, the industrial structure of the PV industry can be divided into two sides: a supply side and demand side. On the supply side, PV cell and module manufacturers are provided with production equipment by equipment suppliers. The value chain of PV modules is composed of poly silicon (raw materials), wafers (intermediate goods), cells (intermediate goods) and modules (finished goods). A PV system is mainly made up of PV modules and inverters. These PV systems are installed by installers (usually builders) or developers. Finally, PV electricity generators (usually large scale power plants or small scale roof-tops) sell their PV electricity to utilities at feed-in rates (usually this price is higher than the average wholesale price of electricity under the feed-in tariff scheme). A main focus of this research is on the growth of PV cell or module manufacturers (bold characters in Figure I-3).

Figure I-3 Main actors in the PV sector



Source: Author

[4] Given the definition of an industry in line with the social system perspective, research institutes, financial systems and policy makers should be included in these main actors (see II.3.1). However, in this sub-section, these actors are excluded for the reasons of clarity.

5. STRUCTURE OF THE THESIS

This thesis consists of nine chapters. Chapters II, III and IV are theoretical parts, while chapters V, VI and VII are empirical parts. Finally, chapter VIII discusses the comparison of the three cases and chapter IX concludes this thesis. Each chapter can be summarised as follows.

Chapter II: Literature Review

In this chapter, existing literature of relevance to the research questions is explored. In particular, varieties of capitalism, developmental state theories, national systems of innovation and catching-up theories are examined in national level approaches, while industry life cycle theories and Pavitt's Taxonomy are explored in industrial level approaches. Then, I attempt to link national level approaches and industrial level approaches through two concepts: comparative advantage and comparative institutional advantage.

Chapter III: Conceptual Framework

Based on the literature review, this chapter attempts to develop a new conceptual framework. Two major concepts are at the heart of this conceptual framework: institutional advantage and necessary functions in the development of the PV industry. After devising a preliminary conceptual framework, I clarify the object of comparative analysis: the crystalline-silicon cell industry in Germany, China and Korea in the 2000s. Then, I suggest a more specified conceptual framework with four necessary functions: demand-pull policy; capital mobilising; process innovation; and cost reduction.

Chapter IV: Methodology

In this chapter, I delineate the data collection and analysis methods that underline this research. In particular, I explain how I selected the three cases and the unit of comparative analysis. In addition, I explain the main data collecting methods (archival and documentary sources and interviews) and data analysis methods (a within-case analysis and a cross-case analysis).

Chapter V, VI and VII: The PV Industry in Germany, China and Korea

These three chapters investigate the development of the PV industry in the context of national political economy. In each chapter, firstly, the political economy and distinctive institutional configurations of each country are discussed. Secondly, it is explained how these institutional configurations influenced the development of the PV industry. Lastly, I attempt to analyse inter-relationships between institutional advantage and the four necessary functions within each case.

Chapter VIII: Comparison of the Three Cases

This chapter identifies causal relationships between institutional advantages and necessary functions for the development of the PV industry through the comparison of the three cases. By doing so, two main conclusions are drawn. One is that market creation was not a generally necessary condition in the development of the PV industry. The other is that capital mobilisation was a core function in developing the PV industry.

Chapter IX: Conclusions

In this last chapter, I clarify the main arguments and outline the contributions, implications and limitations of this thesis. Firstly, I summarise the theoretical arguments and key findings. Then, the theoretical and empirical contributions are discussed and implications for the three countries are drawn. Finally, I deal with the limitations and conclude this thesis suggesting further research.

CHAPTER II LITERATURE REVIEW

1. INTRODUCTION

The aim of this research is to identify the main factors underlying the differences between national growth trajectories of the PV industry in three countries. To explain these trajectories no single theoretical framework will suffice. In this context the aim of this chapter is twofold. The first is to consider a number of possible theoretical perspectives. More specifically I shall consider national level and industrial level approaches that might contribute elements of an explanation. The second is to link these two approaches and ultimately to develop a new conceptual framework for this research. The conceptual framework will be explained in the next chapter.

In this chapter, I shall first explore the 'varieties of capitalism (VoC)' approach and the 'developmental state' theories. The former deals with a divergent economic performance across developed countries, whereas the latter emphasises the role of government rather than market mechanisms in the late industrialisation in East Asia. Moreover, the former argues that the divergence may be regarded as the consequence of the different '*comparative institutional advantages'* between political economies (Hall and Soskice, 2001). In addition, I shall explore the 'national systems of innovation (NSI)' approach and the 'catching-up' theories. The former views the divergence across nations in terms of innovation, while the latter focuses on catching-up processes of backward countries.

Secondly, I shall examine the definition of an industry, then explore the industry life cycle theories and Pavitt's taxonomy. The former investigates the emergence, growth and decline of an industry, while the latter classifies various industries by sectors.

Lastly, I shall explore the two concepts which link national and industrial level approaches: comparative advantage and comparative institutional advantage. The former provides a neoclassical economic reason why a particular country specialises in a certain industry, while the latter provides alternative explanations as to why a certain country achieves better performance in specific types of activities than others.

2. NATIONAL LEVEL APPROACH

In relation to national economic growth or performance, at large, there have been two different perspectives: one is the neoclassical economic approach; and the other is an alternative approach such as institutional, evolutionary or Schumpeterian theories, etc (Dunford, 2010b). In simply terms, while the former focuses mainly on resource allocation and the role of markets, the latter concentrates on growth and development and also pays attention to the role of other institutions such as the state or national systems. Instead of dealing with big debates between the two perspectives[5], I will explore the latter approach in this section because it is more appropriate to analyse industrial dynamics in the context of the national political economy.

Within this perspective, I will examine four approaches: the varieties of capitalism (VoC), the developmental state theories, the national systems of innovation (NSI), and the catching-up theories. Whereas the VoC approach deals with cases of developed countries[6], the developmental state theories consider mainly developing countries, especially the success of East Asian countries. I will also investigate some models which attempt to explain China’s development. The NSI approach explores the similarities and differences across nations in terms of technological innovation, while the catching-up theories examine how backward countries catch up with forerunner countries.

2.1 Varieties of Capitalism

2.1.1 Basic Viewpoints of the Approach

When it comes to the comparative analysis of national economic performance, we can divide it into two different perspectives: one emphasises convergence tendencies, the

[5] However, I will explore briefly the debate on the economic growth of East Asia in the second half of twentieth century in the developmental state theories section, because the debate is deeply associated with the developmental state theories.

[6] Although the varieties of capitalism approach deals with the cases of western developed countries, it argues that it can be applied to understand developing countries (Hall and Soskice, 2001).

other, divergence tendencies (Dunford and Smith, 2000). It is necessary to begin with national level theories which pay attention to the divergence across nations in order to examine the differences of the national growth trajectory of the PV industry.

The VoC approach is one of the divergent capitalism perspectives, because it is more interested in differences and divergence across nations than similarities and convergence (Hall and Soskice, 2001). Basically, it analyses the institutional similarities and differences among the developed political economies after World War II. As a study of comparative capitalism, it regards 'firms' as the crucial actors who deal with coordination problems with other actors within political economy: it adopts 'a relational view of the firm' (Hall and Soskice, 2001, p. 6).

In this approach, '*institutions*' are one of the key concepts to develop its logic. Following North (1990), this approach defines 'institutions as a set of rules, formal or informal, that actors generally follow, whether for normative, cognitive, or material reasons' (Hall and Soskice, 2001, p. 9). I will discuss this concept in detail in the next chapter (III.3.1).

After clarifying the meaning of the institutions, very important viewpoints can be deduced from this approach. Firstly, the institutional configuration is one of the major determinants of the firm's behaviour. This approach argues that differences of the institutional configuration in the political economy 'generate systematic differences in corporate strategy' (Hall and Soskice, 2001, p. 16) across nations, especially liberal market economies and coordinated market economies.[7] In other words, firms are embedded in a nation-specific institutional structure, thus their activities and performance can be largely influenced by the national institutional framework. I will describe this categorisation of market economies in the next sub-section (II.2.1.2).

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[7] Hall and Soskice (2001) provide a simple evidence for their argument. "For instance, the data that Knetter (1989) has gathered are especially interesting. He finds that the firms of Britain, a typical LME [liberal market economy], and those of Germany, a CME [coordinated market economy], respond very differently to a similar shock, in this case an appreciation of the exchange rate that renders the nation's goods more expensive in foreign market. British firms tend to pass the price increase along to customers in order to maintain their profitability, while German firms maintain their prices and accept lower returns in order to preserve market share."(Hall and Soskice, 2001, p. 16)

Secondly, the concept of '*comparative institutional advantage*' can be used to explain the different patterns of specialization of production or products across nations. Hall and Soskice (2001) suggest this concept to explain 'why particular nations tend to specialize in specific types of production or products' (p. 37). This concept is also explored thoroughly in the next sub-section (4.2), because it is one of the major concepts of the conceptual framework.

These two viewpoints are essential for analysing the German, Chinese and Korean cases: the systemic influence on local firms of national institutions and the concept of comparative institutional advantage. Thus, this approach is the starting point for this research. Furthermore, this approach offers a categorisation of national political economies along with the pattern of firms to resolve the coordination problems. This categorisation, which will be dealt with below, is suitable for examining the German political economy.

2.1.2 Liberal Market Economies and Coordinated Market Economies

The VoC approach divides national political economies into two ideal types of economies: a liberal market economy (LME) and a coordinated market economy (CME). Hall and Soskice (2001) explain this typology as follows:

> In *liberal market economies*, firms coordinate their activities primarily via hierarchies and competitive market arrangements. […] In *coordinated market economies*, firms depend more heavily on non-market relationships to coordinate their endeavors with other actors and to construct their core competencies (Hall and Soskice, 2001, p. 8).

In other words, firms tend to solve coordination problems mainly through market mechanisms in a context of competition and formal contracting in LMEs, while firms work mainly through non-market institutions such as 'powerful business or employer associations, strong trade unions, extensive networks of cross-shareholding, and legal or regulatory systems designed to facilitate information-sharing and collaboration' (Hall and Soskice, 2001, p. 10) in CMEs. Furthermore, these concepts provide a broader institutional context so that other comparative analysis can be undertaken more effectively. For example, varieties of corporate governance such as 'the shareholder and stakeholder models' are closely related to the taxonomy of LME and CME (Vitols, 2001). In Germany, which is regarded as a representative case of CMEs, the stakeholder model prevails more than the shareholder one; whilst in the UK, which is regarded as a representative case of LMEs, the opposite is true (Vitols, 2001).

In line with the example, the comparative analysis within the context of LMEs and CMEs can be applied to the varieties of renewable energy policy regime. A feed-in tariff scheme, which relies more on non-market mechanisms than on market ones, is compatible with CMEs, whilst a tradable certificates or renewable portfolio standard, which are regarded as market-oriented schemes, are compatible with LMEs. In fact, the feed-in tariff has been adopted in Germany, whereas the renewable portfolio standard has been adopted in most of the states of America and the tradable certificate was adopted in the UK.[8]

However, it should be noted that there are some limits to the VoC approach when applying to this thesis. Firstly, the comparative setting of the thesis is not a comparison between LMEs and CMEs, because China and Korea can also be categorised as CMEs in that two economies have a tendency to rely more on non-market institutions than on market mechanisms, as I will discuss later. Thus, even though the model of CMEs can identify fully the features of the German economy, it should be applied to the analysis in the context of comparison between Germany, China, and Korea. Secondly, the model of CMEs is unlikely to be sufficient to explain the political economies of China and Korea, thus it is necessary to explore other approaches such as the development state theories in the next sub-section (2.2). Lastly, although technology transfer and innovation are one of the main issues in this study, in particular in China and Korea because of their developmental characteristics, this approach is unlikely to deal with this issue fully. Thus, these innovation and catching-up issues will be explored in sub-sections 2.3 and 2.4.

2.2 Developmental State Theories

[8] The tradable certificate scheme was changed to the feed-in tariff scheme in the UK in 2010 (EPIA, 2010).

2.2.1 Free Market versus Developmental State

There has been much debate on how to account for the rapid economic growth of East Asia in the second half of the twentieth century (Amsden, 1989; Wade, 1990; World Bank, 1993; Stiglitz and Yusuf, 2001; Chang, 2006; Pirie, 2008; Yin and Chang, 2009). In simply terms, one side of the debate are neoclassical economists; the other side are the revisionists or alternative theorists.

According to neoclassical economists, the fast economic growth of East Asia is attributed to the establishment of free market and free trade mechanisms in their economic systems (World Bank, 1993)[9]. In other words, the East Asian governments' attempts to 'get the price right' resulted in low relative price distortions and efficient allocation of resources. Moreover, the governments supported industries on the basis of comparative advantage and made efforts to integrate domestic production markets into international markets (Yin and Chang, 2009). Thus, local industries struggled to survive under the international market force and those who were based on their comparative advantage accomplished global competitiveness.

However, Amsden (1989) and Wade (1990) disagree with the neoclassical theorists on the basis of their case studies, Korea and Taiwan, respectively. They argue that the role of the state was more important than that of the market in the process of late industrialisation in East Asia. In the Korean case, Amsden (1989) argues that the Korean government 'set relative prices deliberately "wrong" in order to create profitable investment opportunities' (p. 14). Even though this type of government intervention created rents, the Korean government utilized them as performance-based incentives,

[9] The World Bank report (1993) argues that its 'market-friendly view' lies between the neoclassical and revisionist views (p. 84). However, in view of the broader picture, the market-friendly view can be included within the neoclassical view in that it argues that government intervention should not go beyond market mechanisms. Furthermore, Paul Krugman (1997) argues that Asian growth was 'mainly a matter of perspiration rather than inspiration – of working harder, not smarter' (cited in Yusuf, 2001, p. 5). In other words, total factor productivity (TFP) 'made a negligible contribution to growth in much of industrializing East Asia. The principal drivers of growth were primarily physical capital followed by human capital' (Young, 1994; Kim and Lau, 1994 cited in Yusuf, 2001, p. 15). However, Stiglitz (2001) points out technical issues of growth accounting and argues that 'the total factor productivity debate is much ado about nothing' (p. 512). I agree with Stiglitz and will follow his view in this thesis.

exercising discipline over the private sector (Amsden, 1989).

In addition, Wade (1990) criticises the theory of comparative advantage in that it 'covers only the effects of once-and-for-all changes in trade restriction. It does not specify a casual mechanism linking realization of comparative advantage of higher growth[10]' (p. 14). He acknowledges the East Asian political arrangements as authoritarian corporatism (Wade, 1990). This characteristic of political regimes provided the basis for market guidance. The regimes guided the market using a set of economic policies which resulted in higher levels of productive investment than would have occurred with free market policy (Wade, 1990).

Furthermore, Pirie (2008) argues that the Korean developmental state should be analysed in the context of supranational political and economic structures such as the Cold War security system and the Japanese-dominated regional economy. In addition, he stresses that Korea's developmental process was a '*national* capitalist development' (p. 2) rather than simply a growth or development (Pirie, 2008).

2.2.2 China's Development Models

Up until now, it seems that no single theory or model can explain the success of China's development process entirely. Thus, I will explore three main issues related to China's development: a transition economy through gradualism, a rural industrialisation by local corporatism, and foreign direct investments with a significant involvement of overseas Chinese[11]. As a whole, these three issues are more compatible with the developmental state theory than the neoclassical economic theory, because they tend to give more weight to non-market mechanisms than to market ones.

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[10] The relationship between industrial upgrading and comparative advantage is dealt with in a recent debate (Lin and Chang, 2009). Lin argues that industrial upgrading should conform to current comparative advantage, whilst Chang disagrees with him in that the East Asian experience was not compatible with his argument (Lin and Chang, 2009).

[11] Indigenous companies, especially large SOEs which were supported by the state via strategic policies, also played a part in China's economic development (Nolan, 2001; Zeng and Williamson, 2007). However, I will focus on these three issues because these issues are distinctive characteristics of China's development compared to other East Asian cases.

2.2.2.1 Transition Economy: Shock Therapy versus Gradualism

A transition from a planned economy to a market economy has been one of the main issues surrounding economic reforms in China, Eastern Europe and the former Soviet Union. However, the economic ways were totally different between China and Eastern Europe and Russia: gradualism[12] in China; shock therapy in Eastern Europe and Russia (Lin et al., 1996; Buck et al., 2000).

In particular, economic reform in Russia was comprehensive, top-down and overnight. Above all, rapid industrial privatisation was implemented through the 'voucher privatization of manufacturing firms' in order to 'achieve the State's withdrawal from industry and to achieve a rapid, irreversible switch to private ownership and control' (Buck et al., 2000, p. 380).

By contrast, the approach of economic reform in China was 'piecemeal, partial, incremental, and often experimental' (Lin et al., 1996, p. 201). Rather than privatisation of state-owned enterprises (SOEs), 'the Chinese government permitted a variety of ownership forms, including firms collectively owned by local governments, foreign-invested firms and new private start-ups' (Buck et al., 2000, p. 381).

The gradualist characteristic of the reform processes of China has some common characteristics with the developmental state theories. As I discussed above, the political arrangements of developmental state was argued as authoritarian corporatism (Wade, 1990). In fact, the Chinese Communist Party has maintained central control and avoided democratic reforms of political institutions unlike in Russia (Buck et al., 2000). Thus, gradual reform processes in China may be attributed partly to the authoritarian feature of the Communist Party regime[13]. Furthermore, the gradual reform approach has preferred various combinations of institutional mechanisms to the market ones.

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[12] This characteristic of China's economic reform is well expressed by the Deng Xiaoping's famous phrase of 'groping for stones to cross the river (*Mo zhe shi tou guo he*)' (Nolan, 2004, p. 1).

[13] On the other hand, it is argued that the main causes of the gradualist characteristic of China's reform were pre-reform conditions, culture and political, social and economic institutions (Buck et al., 2000).

2.2.2.2 Local State Corporatism: Rural Industrialisation

The developmental state theories seem to be applied to China's economic growth without many modifications because the state, the central and local governments, played a major role in the process of industrialisation[14]. However, in the context of China's industrialization, it is argued that a local-level analysis is more appropriate than a national-level analysis, because local political and economic institutions were more helpful for local firms than the central ones under the decentralised political and economic system (Oi, 1995; Oi, 1999; Thun, 2006).

In fact, a rural industrialisation is one of the distinctive features of China's industrialisation: township and village enterprises (TVEs) have contributed much to the economic growth of China (Oi, 1999; Lin and Yao, 2001), as I will discuss in detail in the chapter of the Chinese case. Neoclassical economists might argue that rapid economic growth in rural areas is attributable to the huge amount of labour input or the introduction of market forces after the economic reform. However, the 'local state corporatism' model argues that the rural industrialisation was basically a kind of local state-led development (Oi, 1995; Oi, 1999).

Based on the legacy of the Maoist system, local officials who had a high degree of discipline promoted rapid economic development of their localities under the economic reform (Oi, 1999).

> Working within a strong bureaucratic system, local government at the country, township, and village levels used its official position and administrative resources to foster the development of local enterprises, first collectively owned firms and eventually private ones as well. At the township and village levels, cadres used their administrative authority to mobilize resources within their communities to fund collectively owned rural industry directly, redistributing capital and pooling risks (Oi, 1999, p. 96).

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[14] Peter Nolan (2004) argues that the role of the state has been critical in China's economic growth:

> My own view is that the reason China has been so successful is that despite great strains and numerous policy shortcomings, the state has continued to play a critical role in maintaining social stability, resolving problems of market failure, regulating the distribution of income, wealth and life opportunities, and regulating the way in which China interacts with the global economy (Nolan, 2004, p. 3).

More importantly, the fiscal reforms of China have provided local officials with incentives to encourage faster economic growth of their localities than others (Oi, 1999).

However, in terms of the difference between free market and developmental state, local state corporatism[15] is much closer to the latter than the former, because it emphasises the role of local cadres such as local government officials and communist party officials rather than that of market forces.

2.2.2.3 The Overseas Chinese Model

The overseas Chinese[16] economy, mainly in Taiwan and Hong Kong, relied heavily upon small family-owned businesses. The behaviour of overseas Chinese firms can be characterised as autocratic patriarchal management, fast response to changing global market niches, overseas family connections and returnees from study or work abroad (Hobday, 1995).

Hobday (1995) describes how to function the overseas Chinese-style personal connections, so-called *guanxi*, in the global economy as follows:

> Today's worldwide *guanxi* enable Chinese businesses to match consumer demand in the US with production in China and Taiwan. Typically, the patriarch controls the finances from Hong Kong or Taiwan. His 'number-one-son' manages the factory in China, Thailand or Malaysia. Having been to a university in the US, 'number-two-son' may well work in California, assessing new computer innovations (Hobday, 1995, p. 22).

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[15] When the range of locality is extended to city or provincial level, local state corporatism is similar to developmental state cases in terms of size of economy. For example, the GDP of Guangdong Province (USD 515 billion) was more than half of that of Korea (USD 929 billion) in 2008 (NBSC, 2009).

[16] Mackie (1992) admits that it is problematic to define the concept of 'overseas Chinese' as 'all people of Chinese descent outside China, regardless of their nationality, status or length of sojourn abroad' (Mackie, 1992, p. 41). Some researchers use the term broadly including Chinese descendents in Southeast Asia such as Thailand and Indonesia, however, I will use the term more narrowly in this thesis for the reason of simple and concise explanation, that is, overseas Chinese economy is mainly regarded as Taiwan, Hong Kong and Singapore.

More importantly, the overseas Chinese economy has played a key role in the uprising of the mainland Chinese economy since the economic reform. In particular, Chinese diaspora capital acted as a '"matchmaker" that facilitated the encounter of foreign capital and Chinese labor, entrepreneurs, and government officials' (Arrighi, 2007, p. 351). Furthermore, Arrighi (2007) argues that the overseas Chinese economy has benefited from access to the mainland Chinese economy compared with foreigners as follows:

> The overseas Chinese, […], could bypass most regulations, thanks to familiarity with local customs, habits, and language, to the manipulation of kinship and community ties – which they strengthened through generous donations to local institutions – and to the preferential treatment that they received from CCP [Chinese Communist Party] officials (Arrighi, 2007, p. 352).

Therefore, the overseas Chinese model explains how the overseas Chinese economy is due to rapid industrialisation of the mainland China.

2.3 National Systems of Innovation

2.3.1 Basic Viewpoints of the Approach

Another comparative approach to explain the divergence across nations is the national systems of innovation (NSI) approach which has been developed by neo-Schumpeterians. The emergence of the NSI approach goes back to the works of Freeman (1987), Lundvall (1992), and Nelson (1993) (Shin, 1996). This approach examines the institutions and mechanisms supporting technical innovation and economic performance in various countries (Nelson and Rosenberg, 1993). Compared to the VoC approach, the NSI approach highlights how technical innovations occur within the national context and how national systems differ from each other in view of innovation. Thus, *innovation* is one of the key concepts of the NIS approach.

Even though it is not easy to define the concept of innovation[17], it is necessary to clarify

[17] Another way to approach the concept of innovation is to classify the types of innovation.

what innovation is in order to set the boundaries of this research. According to the text book definition of innovation, the concept of innovation can be described as 'the first attempt to carry [a new product or process] out into practice' (Fagerberg *et al*., 2005, p. 4). With regard to 'the first attempt', it can be interpreted as the first firms to bring a new product to market or adopt a new process in production. However, in order not to limit this thesis to the behaviour of leading firms in the world or to the most advanced scientific researches, it is necessary to interpret the concept of innovation in a comprehensive sense. From this perspective, Nelson and Rosenberg (1993) suggest the concept of innovation can be broader as follows:

> [W]e interpret the term rather broadly, to encompass the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, if not to the universe or even to the nation (p. 4).

In line with this perspective, the OECD 'Oslo manual' divides innovation into three categories: innovations new to the world; innovations new to the market; and innovations new to the firm (Bell, 2009, p. 12). In this thesis, I have followed this broader definition of innovation so that I can include latecomer firms in developing countries as well as leading firms in developed countries.

On the other hand, the nature of innovation needs a *systemic* approach in that innovation is the result of complex relations and interactions between actors such as firms, customers and research institutes. These relations and interactions can be 'characterized by reciprocity, interactivity, and feedback mechanisms in several loops' (Edquist, 1997). Focusing on the interactive feature of innovation, Lundvall (1992) argues that 'interactive learning' between user and producer is the focusing device of the NSI approach toward a theory.

Schumpeter refers to examples of innovation as follows: new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organize business (Fagerberg, 2005, p. 6). Concerning the first two of these, Schmookler argues that the distinction between product innovation and process innovation: the former is creation or improvement of products, the latter is how to produce in better way (Fagerberg, 2005, p. 7). In view of the continuity of innovation process, the concept can be divided into radical innovation and incremental one: this means continuous improvements, while the other means the introduction of a totally new product or process (Fagerberg, 2005, p. 7-8).

The systemic nature of innovation can be understood well by contrasting it to the linear model[18]. Kline and Rosenberg (1986) point out that the linear model has serious defects in interpreting innovation. Some innovation derives from scientific research, however, most of the innovation of firms comes from efforts to respond to market demand. Furthermore, the linear model cannot explain the many feedbacks and loops within the innovation process (Kline and Rosenberg, 1986).

Generally, a system is constituted by a number of actors or elements and by the relationships or interactions between the elements (Lundvall, 1992; Nelson, 1993). According to the NSI literature, main actors of innovation systems can be identified as follows: first of all, firms are main actors because most of innovations are originated by the firms; secondly, universities and research institutes play a major role in innovation because science and technology is one of the sources of innovation; thirdly, users or customers are also main actors considering ‘user-producer interactive learning’; Lastly, governments and government agencies are actors because they facilitate innovations (Lundvall, 1992; Nelson, 1993).

Lastly, it is worth examining the concept of a *national* system in the NSI approach. As business and technology become transnational, the meaning of national borders in innovation literature becomes blurred. However, due to the range of technology policies, national education systems, national institutions, etc., there are still significant national differences which affect how technical advance proceeds (Nelson and Rosenberg, 1993).

However, the NSI approach is unlikely to provide a general conceptual framework to apply for comparative empirical research (Shin, 1996). Even though Lundvall (1992) suggests ‘interactive learning’ as a theoretical device for comparative studies, Nelson (1993) posits careful description, comparison and understanding of cases before theorizing and then proving the theory as follows:

> Nelson does not deny the need for a theory or a common thread to synthesise case studies. But it is a remote objective at this stage when careful empirical studies have not been

[18] ‘Basically, ‘‘the linear model’’ is based on the assumption that innovation is applied science. It is ‘‘linear’’ because there is a well-defined set of stages that innovations are assumed to go through. Research (science) comes first, then development, and finally production and marketing’ (Fagerberg, 2005, p. 8).

> sufficiently accumulated. He, […], assumes that the principal task of researchers is to concentrate on descriptions of individual phenomena and compare similarities and differences across countries, before they arrive at a more general understanding. On the other hand, Lundvall, […], emphasises the importance of theory for understanding. He argues that any theory is basically a 'focusing device' which 'brings forward and exposes some aspects of the real world, leaving others in obscurity'. And he proposes 'interactive learning' as his focusing device for understanding the NSI (Shin, 1996, p. 34).

Therefore, it can be said that the general conceptual framework of the NSI approach 'is still at an exploratory stage (Shin, 1996, p. 37). Thus, I will examine other theories further in order to compensate these limitations.

2.3.2 The Latecomer Firm Model in East Asia

Hobday (1995) puts forward the East Asian latecomer firm model which shows the institutional mechanisms of technological learning by latecomer firms. He examines how latecomer firms of four East Asian countries (Korea, Taiwan, Hong Kong and Singapore) manage to catch up with leading firms of more advanced countries in the electronics sector. His main focus is the interactions between latecomer firms and multinational companies (MNCs) at the firm-level[19].

To begin with, Hobday (1995) defines the latecomer firm as 'a manufacturing company (existing or potential) which faces two sets of competitive disadvantages in attempting to compete in export markets' (p. 33). One is a technological disadvantage which results from isolation from the main international sources of technology and R&D. The other is a marketing disadvantage because the latecomer firm is dislocated from the mainstream international markets. However, latecomer firms have substantial cost advantages over leading firms.

In order to overcome the technological barrier, latecomer firms learn and acquire foreign technology through various institutional channels. Hobday (1995) sets out

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[19] Although the latecomer firm model focuses on the firm-level, I will include this model in the national level approach, because it provides meaningful insights into understanding the catching-up process of electronics sector within the East Asian national context.

technology acquisition channels of latecomer firms as shown in Table II-1.

Table II-1 Mechanisms of foreign technology acquisition by latecomer firms

Foreign direct investment (FDI)
Joint ventures
Licensing
Original equipment manufacture (OEM)
Own-design and manufacture (ODM)
Sub-contracting
Foreign and local buyers
Informal means (overseas training, hiring, returnees)
Overseas acquisition/equity investments
Strategic partnerships for technology

Source: ‘Innovation in East Asia’ (Hobday, 1995, p. 35)

One of the most important institutional channels for East Asian latecomer firms was original equipment manufacture (OEM[20]). Under OEM, a latecomer firm produced goods in accordance with the precise specification of a foreign MNC. Then, the foreign MNC sold the product under its own brand name using its own distribution channels. Thus, the latecomer firm was able to overcome marketing barriers without investing in marketing and distribution. Moreover, the foreign partner usually helped the latecomer firm in selection of capital equipment and the training managers, engineers and technicians of the latecomer firm. Therefore, OEM functioned as a training school for latecomer firms, enabling latecomer firms to acquire basic capacity to assimilate manufacturing and design technology. Sooner or later, latecomer firms gained more and more control over their production processes. For example, they were able to design their own products and begin to research and develop new products and process innovation. Finally, they had competitive R&D capabilities and reached the same level

[20] ‘OEM is a specific form of subcontracting that evolved out of the joint operations of TNC [transnational company] buyers and NIE [newly industrialising economy] suppliers. Under OEM, the finished product is made to the precise specification of a particular buyer (or TNC) who then markets the product under its own brand name, through its own distribution channels. OEM takes a variety of forms and has evolved considerably since the 1960s. … The term OEM began to be used in the 1950s by US computer makers who used East Asian suppliers to produce equipment for them. It was later adopted by US TNCs in the 1960s, which used local firms to assemble and test semiconductors. Today, the term has acquired a variety of meanings (some use OEM to refer the local supplier). To avoid confusion, … , the term OEM refers to the subcontracting system in which firms cooperate, rather than to the buyer or supplier of equipment’ (Hobday, 2000, p. 133).

as leaders in terms of technological capability (Hobday, 1995).

Hobday (1995) argues that the innovation pattern of East Asian latecomers is different from that of Western leaders. As traditional models of innovation indicate, a typical sequential order of innovation activities of leading firms is R&D, product innovation and process innovation, however, that of East Asian latecomers is the reverse, i.e assembly first, then incremental improvements of process, and finally R&D.

Although the implications of Hobday's arguments are considerable, his study cannot encompass the whole national system in the context of East Asian countries because he largely focuses on firm-level learning. Therefore, this point will be explored in the catching-up theories as below.

2.4 Catching-up Theories

2.4.1 Basic Viewpoints of the Approach

While the VoC approach focuses on the 'comparative institutional advantage' across nations, the catching-up theories are interested in the process of building up 'new institutional instruments' which are able to narrow the gap between forerunner and latecomer economies. Overall, the catching-up theories can be divided into two main streams: one is Abramovitz's general approach; the other is Gerschenkron's specific approach (Shin, 1996).

Abramovitz (1979; 1986) proposes a universal concept of '*social capability*' in order to explain general process of catching-up (cited in Shin, 1996). He identifies a country's social capability as 'technical competence, for which […] years of education may be a rough proxy, and its political, commercial, industrial, and financial institutions, which I characterized in more qualitative ways' (Abramovitz, 1989, pp. 222-223). Using this concept, he argues that 'a country's potential for rapid growth is strong not when it is backward without qualification, but rather when it is technologically backward but socially advanced' (Abramovitz, 1989, p. 222). Furthermore, he attempts to explain the post-war catching-up process of OECD follower countries, regarding the high level of social capability as a cause for catching-up (Shin, 1996).

However, there are some limitations to Abramovitz's catching-up theory. Firstly, the concept of social capability is too ambiguous to apply other empirical research (Shin, 1996). Secondly, if 'the process of enlarging social capability is separated from that of technological catching-up, the former can be regarded as a general precondition for the latter across time and space' (Shin, 1996, p.15). However, some examples of catching-up such as the East Asian new industrialised economies (NIEs) do not fit with Abramovitz's argument.

By contrast, Gerschenkron adopts an explanatory schema rather than proposing some universal concepts (Shin, 1996). He points out the half-truth of the view of 'prerequisites' for economic development, furthermore, he argues that 'the great spurt of industrial development occurred despite the lack of these 'prerequisites'' (Gerschenkron, 1963 cited in Shin, 1996, p. 21). Rather, the very existence of a more advanced country provides latecomers with what amounts to prerequisites for the development of the forerunner (Shin, 1996). Therefore, 'the central focus of Gerschenkron's analysis of late industrialisation is on the question of how those often 'missing' prerequisites in latecomers are created or substituted for through specific institutional responses' (Shin, 1996, p. 22). For example, the Korean *chaebol*-led catching-up process can be understood in terms of substituting institutions along the development path.

In principle, Gerschenkron's comparative schema, a three-country paradigm, mainly derived from the historical experience of Germany and Russia's catching-up with Britain in the latter half of the nineteenth century, utilising an organising concept of the 'degree of backwardness' (Gerschenkron, 1962). In the process of catching-up, latecomers attempted to devise functional substitutes for the institutions of the forerunner, such as 'investment banks' in Germany and 'the state' in Russia (Gerschenkron, 1962).

When it comes to the tension between theory and reality, Gerschenkron's schema is neither a universal proposition nor a descriptive history, but locates somewhere between them. 'Its strength is in demonstrating different strategic factors across countries; its weakness lies in the limits of its application' (Shin, 1996, p. 24). Thus, it mainly explains a differentiated system of a different latecomer in a different time. As it applies to the East Asian catching-up experiences, the Gerschenkronian-type catching-up strategy is likely to fit for the Japanese and Korean cases. It can be regarded as a 'substituting strategy' in that the strategy of latecomers is establishing substitutes for the 'prerequisites' of development in order to compete with forerunners (Shin and Chang, 2003). However, this is not the case for some East Asian countries such as Singapore and Taiwan, as I will discuss below (II.2.4.2). Thus, another type of catching-up strategy is needed like a 'complementing strategy' to explain latecomers' attempts to develop mainly through exploiting complementary relations with forerunners rather than attempting to directly compete with them (Shin and Chang, 2003).

2.4.2 East Asian Catching-up Models

As I mentioned earlier, the catching-up strategy can be divided into two strategies in relation to the relationship between latecomers and forerunners: one is a substituting strategy; the other is a complementing one.

Shin and Chang (2003) put forward 'the East Asian catching-up models' based on this categorisation. They assume that the comparative analysis between the US, Japan, and Korea is suitable for applying the three-country paradigm suggested by Gerschenkron. They argue that Japan and Korea adopted the Gerschenkronian substituting strategies, 'focusing on building internationally competitive 'local' industries' (Shin and Chang, 2003, p. 11) in order to compete with leading industries in more advanced economies.

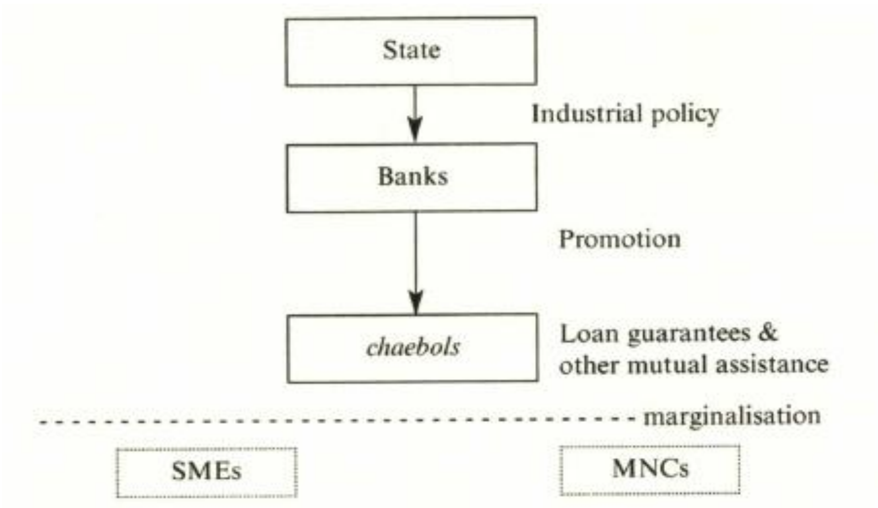
In particular, they focus more on the Korean case, an 'extremely backward' country compared to Japan. They pay attention to three main players in Korea: the government, commercial banks and the *chaebols*, the Korean version of family-owned conglomerates. In a developmental stage, the Korean government nationalised commercial banks and controlled their preferential loans to firms under its industrial policy. Shin and Chang (2003) describe the substitution strategy in Korea as follows:

> The state designated strategic industries and picked up companies or business groups to

> undertake the task of building these new industries whilst providing them with subsidies and protections. The state-banks-*chaebol* nexus thus became the central feature of the Korean economic system (Shin and Chang, 2003, p. 13).

This is illustrated in Figure II-1. The state-banks-*chaebol* nexus played the role of substituting institutions similar to the German investment banks and the Russian state in the late nineteenth century in Europe. In other words, these special institutions mobilised resources to realize a catching-up strategy in the process of economic growth in Korea. Thus, it can be regarded as the specific institutions in the Korea's catching-up process.

Figure II-1 Korea's nationalistic model

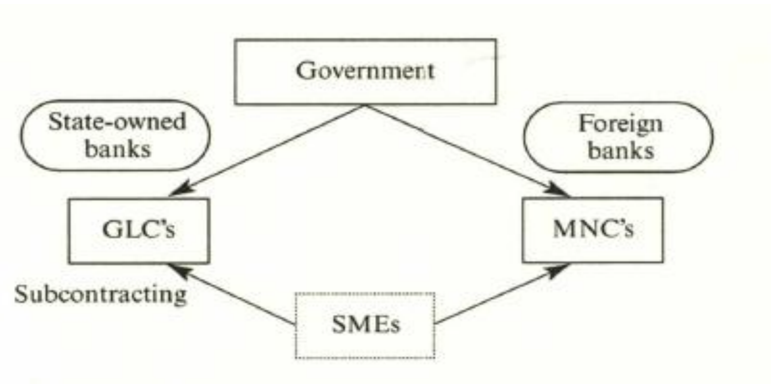


Source: 'Restructuring Korea Inc.' (Shin and Chang, 2003, p. 14)
SMEs (Small Medium-sized Enterprises)
MNCs (Multi-National Companies)

By contrast, the pattern of catching-up in Singapore and Taiwan is to some extent different from the Gerschenkronian substituting strategy. Singapore and Taiwan also can be regarded as 'extremely backward' countries compared to Japan in the second half of the twentieth century. However, they underwent industrialisation mainly through exploiting complementary relations with bigger forerunner countries rather than attempting to directly compete with them (Shin and Chang, 2003). The emergence of the Taiwanese or Singaporean complementing strategy, which was rare in the nineteenth century, is mainly influenced by 'the acceleration of globalisation in the latter half of the twentieth century' (Shin and Chang, 2003. P. 19).

In Singapore, economic development largely relied on foreign MNCs. The Singaporean government was not likely to be very interested in competing with its forerunners. Instead, it provided the MNCs with qualified 'complementary assets' (Teece, 1986) such as infrastructure, human capital, fiscal incentives, etc. in order to attract FDI in Singapore (Shin and Chang, 2003). As MNCs were located in Singapore, the barriers to accessing advanced technologies and of financing industrialisation for local firms were lowered. As a result, the MNCs 'enabled Singapore to export and to systematically acquire technology' (Hobday, 1995, p. 136). On the other hand, Government-linked companies (GLCs), which are public enterprises in Singapore, did businesses in which MNCs were not interested. These characteristics of the Singaporean model are illustrated in Figure II-2. Compared with other East Asian countries, the main feature of Singapore's economic development is 'the most internationalist route for industrialisation' (Shin and Chang, 2003, p. 17).

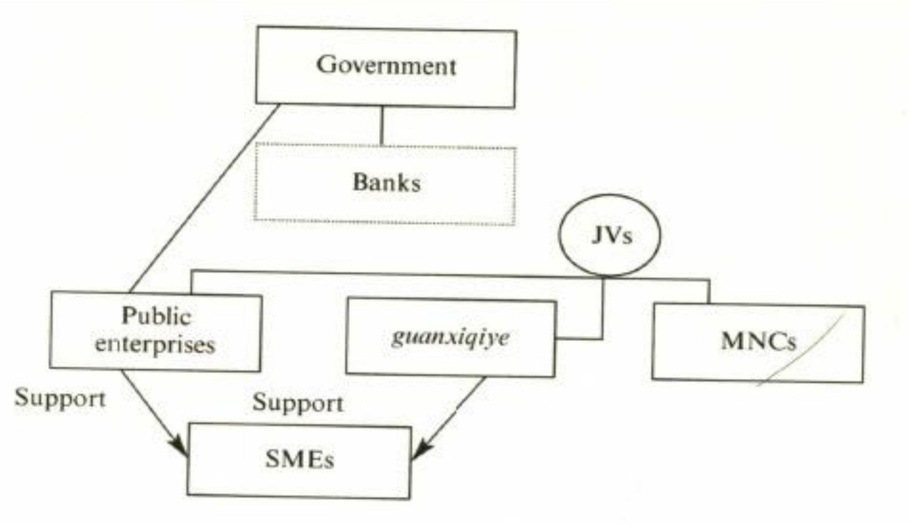
Figure II-2 Singapore's internationalist model



Source: 'Restructuring Korea Inc.' (Shin and Chang, 2003, p. 17)

The Taiwanese developmental path lies somewhere between the Korea's nationalistic one and the Singapore's internationalist one. In contrast to the Korean case, industrial development relied heavily on SMEs in Taiwan (Hobday, 1995). In contrast to the Singaporean government, the Taiwanese government attempted to protect local industries through public enterprises and the *guanxiqiye* (local business groups) in the initial stage of industrialisation. But it changed the orientation of industrial policy from import-substitution industrialisation to attracting MNCs in order to compensate for the lack of big local companies. In addition, ‘the Taiwanese private companies, the *guanxiqiye* or the SMEs, seldom attempted to compete directly with their forerunners in Japan or in the US’ (Shin and Chang, 2003, p. 18). Moreover, the Taiwanese government played a major role in matching local companies and MNCs in the form of Joint Ventures (JVs) where venture capital was needed such as in the semiconductor sector. As a result, the Taiwanese industrial structure is currently based on complex relationships between four major players: the public enterprises, the *guanxiqiye*, the MNCs, and the SMEs. These relationships between four players are shown in Figure II-3. In short, the feature of the Taiwanese economic development summarises as ‘a semi-internationalist path of catching-up’ (Shin and Chang, 2003, p. 18).

Figure II-3 Taiwan’s semi-international model



Source: ‘Restructuring Korea Inc.’ (Shin and Chang, 2003, p. 18)

3. INDUSTRIAL LEVEL APPROACH

Basically, the unit of analysis of this study is an industry under the national political economy, so I will begin with a definition of an industry. In addition, because the focal point of the research is the evolution of industry, I will take an industrial dynamics perspective by examining the industry life cycle (ILC) theories. Furthermore, the characteristics of the evolution of industry may be significantly different across sectors. Thus, I will also deal with Pavitt's taxonomy in the last part of this section.

3.1 Definition of an Industry

In order to understand the evolution of industry, it might be reasonable to start with this question: what is an industry? Traditionally, industrial economists regard an industry as a group of firms that produce similar goods and services. In line with this, Porter (1980) defines an industry as 'the group of firms producing products that are close substitutes for each other' (p. 5). From this perspective, the dynamics of industry is explained by a natural selection process or economic competition. For example, if the rate of return of capital of an industry is higher/lower than a perfectly competitive floor rate of return, firms enter into/exit from this industry[21] (Porter, 1980). This product-class view of industry focuses on market mechanisms or price competition, and is likely to be appropriate to explain the competitive position of a firm in relatively stable periods of an industry (Munir and Phillips, 2002). In this sense, this type of definition of an industry is suitable for neoclassical economic theories.

However, as Schumpeter (1975) pointed out, due to the importance of technological competition rather than price competition in the initial stage of industry emergence, this product-class view does not capture the dynamics of industry at a time of change (Munir and Phillips, 2002). Thus, a more encompassing definition of an industry is needed in order to explain fully industrial dynamics. In other words, 'the traditional

[21] In other words, '[i]nvestors whose long-term returns are below this "free market" return will invest elsewhere, and firms habitually earning less than this return will eventually go out of business. Rates of return higher than this floor rate will stimulate the inflow of capital into an industry either through new entrants or through additional investment by existing competitors' (Van de Ven and Garud, 1989, p. 198).

definition of an industry needs expansion not only to include competing firms, but also many other actors that perform all the functions necessary to develop and commercialize a technological innovation' (Van de Ven and Garud, 1989, p. 201). Thus, they suggest two levels of analysis in order to explain industry emergence: '(1) the motivations and activities of individual firms or entrepreneurs, and (2) the collective level of multiple actors who interact and socially construct an industry' (Van de Ven and Garud, 1989, p. 202).

Therefore, Van de Ven and Garud (2000) suggest that an industry be regarded as a *social system* as follows:

> [A]n industry [should] be viewed as a "social system" which governs, integrates, and performs all of the functions required to transform a technological innovation into a commercially viable line of products or services delivered to customers (p. 492).

As an industry is defined as a social system, Parson's (1964) functional differentiation of subsystems can be applied to analysing industry emergence (cited in Van de Ven and Garud, 1989). Functions of different subsystems of an industry will be discussed in the next chapter (III.3.3 p. 31).

In short, while Porter's definition of an industry emphasises firms, Van de Ven and Garud's definition encompasses other main factors, i.e., research institutes, financial systems, and policy makers as well as firms. Thus, I will follow Van de Ven and Garud's perspective because it is more appropriate in explaining the evolution of the PV industry than the product-class view.

3.2 Industry Life Cycle Theories

3.2.1 Vernon's Theory

Industrial dynamics is one of the main issues of the ILC theories, because they deal with the emergence and evolution of industry (Klepper, 1997). They explicitly consider a time sequence as one of the dimensions, so they analyse how an industry emerges, grows and disappears.

When we trace back to Vernon, he (1966) explains the relationship between a product cycle and international trade and investment. He classifies the phases of a product cycle as new products, maturing products, and standardised products in accordance with a degree of *standardisation* (Vernon, 1966). In the early stage of a new product, it may be standardised at a very low level. As its market grows, a certain degree of standardisation usually takes place. Finally, the standardisation of the product reaches an advanced level (Vernon, 1966).

In the view of the location of an industry, as the standardisation of the product proceeds, the possibility of locating the industry on the less-developed countries grows. This aspect of Vernon's product cycle theory influenced the flying geese model[22] (Kojima, 2000), which explains the shift of mature industries from Japan to other East Asian countries.

3.2.2 Utterback's Theory

In view of the relationship between the pattern of innovation within a firm and the stage of development of industry, Utterback and Abernathy (1975) suggest an integrated theory of innovative process which can be divided into development of production processes and development of products.

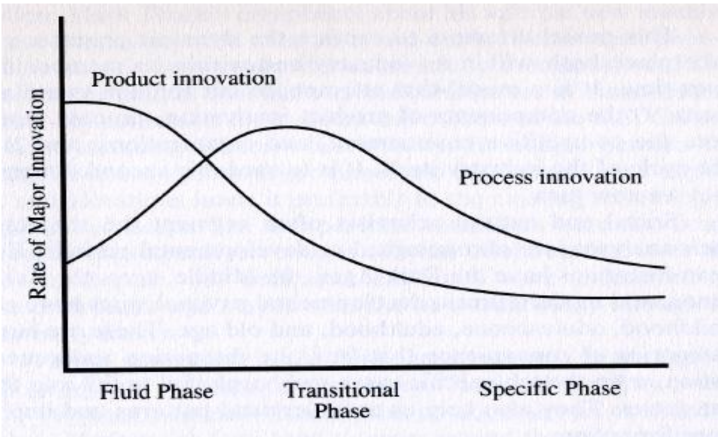
They introduce the concept of '*dominant design'* which means 'the one that wins the allegiance of the marketplace, the one that competitors and innovators must adhere to if they hope to command significant market following' (Utterback, 1994, p. 24). In other words, 'a dominant design is one whose major components and underlying core concepts do not vary substantially from one product model to the other, and the design

[22] This model starts with Japan's economic superiority in the East Asia. It describes that Japan developed first, and played a major role in driving economic and technological development of the region. As wages rose and the currency appreciated in Japan, industries were shifted from Japan to four NICs, then to the second-tier ASEAN economies and China (Hobday, 1995). This explanation on the relocation of matured industries in the East Asia was influenced by Vernon's product cycle theory (Kojima, 2000).

commands a high percentage of the market share' (Afuah and Utterback, 1997, p. 185). Before the dominant design of product is established, various designs of product compete in the marketplace. Thus, firms' strategies emphasise product innovation. When some product design becomes dominant; a *de facto* product standard, firms focus more on process innovation rather than product innovation (Utterback, 1994). Historic examples are the QWERTY keyboard in the typewriter industry and the IBM PC in the personal computer market (Utterback, 1994). Therefore, the emergence of dominant design[23] marks a divide in the pattern of innovation.

Furthermore, Utterback (1994) suggests a three-phase model of an ILC: fluid, transitional, and specific phases. In the *fluid phase*, there is a lot of uncertainty in the technology, market, and product design, thus various products exist and product innovation is vibrant. In the *transitional phase*, a dominant design appears and the focus of firms shifts from product innovation to process innovation. Finally, in the *specific*[24] *phase*, the product is highly standardized and largely undifferentiated, and the production process becomes larger scale and usually uses specialized equipments. These relationships between the pattern of innovation and the developmental stage of industry are depicted in Figure II-4.

Figure II-4 Utterback's three-phase model



[23] On the other hand, pointing out the impreciseness of the notion of a dominant design and the inextricable linkage between product and process innovation, Klepper (1996) proposes a new explanation for the industry life cycle. Focusing on the entry and exit of firms, market structure and technological change, he identifies the regularities of industry evolution. However, I will not deal with his theory because it is unlikely to be relevant to this thesis.

[24] Utterback uses 'the term "specific" rather than "mature" as is used here because the manufacturing of assembled products aims over time at producing a very specific product at a high level of efficiency' (Utterback, 1994, p. 96).

Source: 'Mastering the Dynamics of Innovation' (Utterback, 1994, p. 91)

3.2.3 Van de Ven and Garud's Theory

Formally, the ILC theories mainly focused on the regularities and features of each stage. However, this seems insufficiently to explain how new industries emerge in the formative period. With this in mind, Van de Ven and Garud (2000) propose a new conceptual framework in order to analyse industry emergence referring. This is known as the accumulation theory of change in which they conceptualise each stage as follows:

> *Initiation* is the time when entrepreneurs decide to form a business venture (if successfully launched will become the birthday of the business unit), and *takeoff* is the time when the unit can exist without the external support of its initiators and continue growing "on its own". The period between initiation and takeoff could be called *startup*, where the new unit must draw its resources, competence, and technology from the founding leaders and external sources in order to develop the proprietary products, create a market niche, and meet the institutional standards established to legitimate the new unit as an ongoing economic enterprise. (Van de Ven and Garud, 2000, p.492)

Moreover, Van de Ven and Garud (2000) add 'the gestation period' before the initiation one in explaining the sequence of industry development. The gestation period being when 'basic knowledge is created' through basic science research (Van de Ven and Garud, 2000, p.518).

In summary, the stages of ILC theories can be compared as shown in Table II-2.

Table II-2 Comparison of the stages of ILC theories

Author	First stage	Second stage	Third stage	Key concept
Vernon	New product	Mature product	Standardized product	The degree of standardization
Utterback	Fluid phase	Transitional phase	Specific phase	Dominant design
Van de Ven and Garud	Initiation (prior stage: gestation)	Start-up	Take-off	The accumulation theory

Source: Author

3.2.4 Jacobbson's Model

There have been some attempts to extend the ILC approach to the energy sector, especially the renewable energy sector (Jacobsson and Bergek, 2004; Jacobsson and Lauber, 2006). To begin with, it should be noted that there are distinctive features of the energy sectors compared to other sectors: a huge scale of energy system; a difficulty of market formation for new energy sector; and a strong relationship between the energy sector and institutional arrangements (Jacobsson and Bergek, 2004). Thus, a formative phase of a renewable energy sector may be long, and a transformation of the energy sector from a fossil fuel dominant system to a renewable one may be a highly political process (Jacobsson and Bergek, 2004).

Due to the relatively longer formative period and political sensitiveness of the renewable energy sector, it is important to identify the distinctive characteristics of it as follows:

> We will emphasize four features of this process: market formation, the entry of firms and other organizations, institutional change and the formation of technology-specific advocacy coalitions (a particular form of network) (Jacobsson and Bergek, 2004, p. 819).

These four features have strong causal interrelationships, thus, Myrdal's virtuous circles can be set in motion at a certain level of them (Jacobsson and Bergek, 2004). For example, the development of the German wind and PV industries can be explained by the virtuous circles of the four features (Jacobsson and Lauber, 2006).

3.3 Pavitt's Taxonomy

Pavitt and Rothwell (1976) point out that Utterback and Abernathy's ILC theory ignores significant differences across sectors. Subsequently, Keith Pavitt (1985) develops a taxonomy which refers to the sectoral patterns of technical changes. Pavitt's taxonomy, which has been used as a powerful concept to understand the differences across sectors in terms of technological trajectories, can be summarised as follows:

> He [Pavitt] proposes four types of sectoral patterns of innovative activities: supplier-dominated sectors (textiles, services), in which new technologies mainly come embodied in new components and equipment, and the diffusion of new technologies and learning takes place through learning by doing and using; scale-intensive sectors (automobiles, steel), in which process innovation is relevant and the sources of innovation are both internal (R&D and learning by doing) and external (equipment producers) and appropriability is through secrecy and patents; specialized suppliers (such as equipment producers), in which innovation is focused on performance improvement, reliability and customization, the sources of innovation are both internal (the tacit knowledge and experience of skilled technicians) and external (user-producer interaction), and appropriability comes mainly from the localized and interactive nature of knowledge; and, finally, science-based sectors (such as pharmaceuticals, electronics and so on) which are characterized by a high rate of product and process innovations, internal R&D and scientific research done at universities and public research laboratories and appropriability means of various types, ranging from patents to lead times, learning curves and secrecy (Malerba, 2004, p. 13).

Pavitt's taxonomy has some implications for economic policy makers. For example, when a certain sector is promoted by a certain country, it should be considered whether the features of the innovation process of the sector is appropriate to the country's strengths (Malerba, 2004). In this sense, the main ideas of Pavitt's taxonomy can be applied to identify the features of the PV industry as examined later[25].

[25] Furthemore, based on Pavitt's taxonomy, Malerba (2004) argues sectoral systems of innovation approach. He explains that a sectrol system has three building blocks: knowledge and technology; actors and networks; and institutions. Although this approach fits for the concept of industry as a social system, I will not deal with this approach because it is complex to apply to the conceptual framework in this thesis.

4. LINKING NATIONAL AND INDUSTRIAL APPROACHES

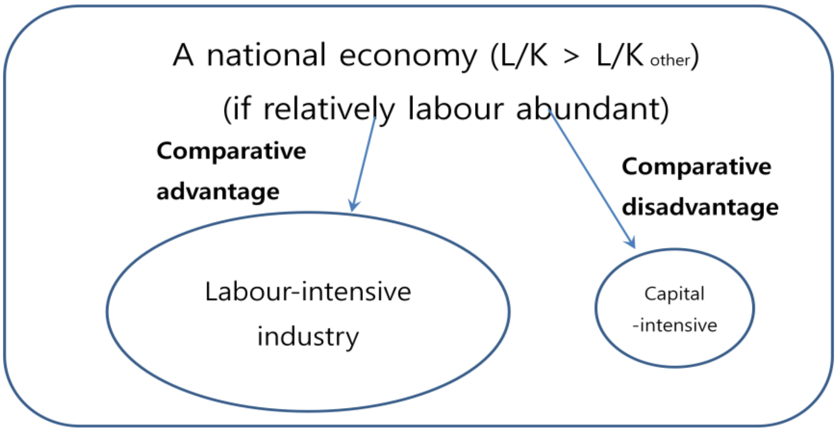
In this section, I will attempt to link the national and industrial level approaches using the two bridging concepts: comparative advantage and comparative institutional advantage.

4.1 Comparative Advantage

In the neoclassical economics, international trade analyses have been based not on the absolute advantage, but on the concept of 'comparative advantage', which was introduced by David Ricardo in *The Principles of Political Economy and Taxation* (1817) (cited in Appleyard et al., 2008).

Early in the twentieth century, the concept was evolved by Heckscher (in 1919) and Ohlin (in 1933) in terms of factor endowments (cited in Appleyard et al., 2008). The Heckscher-Ohlin theorem means that 'the country with abundant capital will be able to produce relatively more of the capital-intensive good, while the country with abundant labour will be able to produce relatively more of the labour-intensive good' (Appleyard et al., 2008, p. 130-131). In this theorem, the concept of comparative advantage links a relative factor abundance of national economy and a factor-intensive industry. This is shown in Figure II-5.

Figure II-5 Linking a national economy and an industry by comparative advantage[26]



Source: Author

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[26] Ricardo assumes a two-nation (England and Portugal) and two-good (wine and cloth) model, and the Heckscher-Ohlin's model assumes a two-nation, two-good and two-factor (e.g., labour and capital) model (Appleyard et al., 2008), but I use one nation here for simplicity.

However, the theory of comparative advantage cannot provide sufficient explanation to technological catching-up or the building process of technological capability, especially on the late industrialisation and industrial upgrading in East Asia in the second half of the twentieth century (Chang, 2007)[27]. In other words, it seems to pay more attention to a static situation than dynamics in long-term. In reality, comparative advantage of a certain country can be changed. For instance, an active government's intervention can change its resource endowments, and then this change can result in the change of comparative advantage. Indeed, the developmental state theory attempts to explain this mechanism (II.2.2 p. 14). Also, the new economic geography points out that '[most] of the resources on which development depends are result of previous human activity' (Dunford and Greco, 2006, p. 38). Thus, resource endowments can be created historically and can be changed by human activities. Furthermore, in terms of 'revealed comparative advantage', it is argued that China's comparative advantage has seemed to be changed from low-technology goods to higher-technology ones through analysing its trade data (Li, Dunford and Yeung, 2011). Therefore, it is necessary to find an alternative concept to link national economic development and industrial dynamics in the long-term.

4.2 Comparative Institutional Advantage

The VoC approach is critical of the theory of comparative advantage[28], and then it offers the concept of 'comparative institutional advantage' (Hall and Sosckice, 2001) as follows:

> We still need a theory that explains why particular nations tend to specialize in specific types of production or products. We think that such a theory can be found in the concept of *comparative institutional advantage*. The basic idea is that the institutional structure of a particular political economy provides firms with advantage for engaging in specific types of activities there. Firms can perform some types of activities, which allow them to produce some kind of goods, more efficiently than others because of the institutional

[27] Furthermore, Chang (2007) points out that the assumptions of 'the same technology' and 'perfect factor mobility' are unrealistic (p. 70-71).

[28] Hall and Soskice (2001) refer to 'the expansion of intra-industry trade and increases in the international mobility of capital' (p. 36).

> support they receive for those activities in the political economy, and the institutions relevant to these activities are not distributed evenly across nations (Hall and Soskice, 2001, p. 37).

This concept may be applied not only to firms' production activities, but also to firms' fund raising and upgrading technological capacity. Furthermore, the range of this concept can be extended from firms' activities to industrial dynamics or industrial upgrading. If a certain country aims at industrial upgrading more relevant to its comparative institutional advantage, the possibility of success of the industrial upgrading will increase. Thus, varieties of national trajectories of a certain industry can be explained by the relationships between comparative institutional advantage and characteristics of the industry.

Furthermore, the VoC approach argues that the concept is not 'absolute advantage' but 'comparative advantage' as follows: '[w]e seek institutional features that might confer comparative advantage and, thus, be better suited to explaining cross-national patterns of product or process specialization' (Hall and Soskice, 2001, p. 38). I agree that the concept of institutional advantage is far from absolute advantage, thus I will apply this concept to the cross-national comparison in this study. Furthermore, I will discuss the concreteness of institutional advantage in the next chapter (conceptual framework chapter).

5. CHAPTER SUMMARY

This chapter has discussed the literature survey of this study. For the literature review, three approaches have been explored: a national level, an industrial level, and concepts which link these two levels.

Firstly, in the national level approach, the taxonomy of capitalism such as liberal market economies (LMEs) and coordinated market economies (CMEs), the role of developmental states in late industrialisation in East Asia and China, the role of institutions in national systems of innovation (NSI), and differentiated institutional instruments in the catching-up processes of backward countries have been examined.

Secondly, an industry, which can be interpreted as a social system, is argued to have evolutionary patterns and stages by industry life cycle (ILC) theories. In particular, renewable energy industry is argued to have a long formative phase by Jacobbson. On the other hand, Pavitt points out the different patterns of innovation across sectors.

Lastly, linking concepts between national and industrial level approaches have been discussed. Comparative advantage, which is the basis of neoclassical trade theory, has limitations to explain industrial dynamics, while comparative institutional advantage is identified as one of organising concepts in that it may result in different economic performance across nations and sectors. Based on this concept, a preliminary conceptual framework will be constructed in the next chapter.

CHAPTER III CONCEPTUAL FRAMEWORK

1. INTRODUCTION

The aim of this chapter is to develop a new conceptual framework for this research and to examine some questions concerning comparative analysis.

Firstly, I shall explore briefly the tension between theory and reality. Then, based on the literature review in the previous chapter, three major concepts will be dealt with: institutions; institutional advantage; and necessary functions in development of an industry. The last concept will bridge institutional advantage of a nation and evolution of a certain industry. After clarifying the meaning of the major concepts, I shall attempt to suggest a preliminary conceptual framework. The central argument based on the conceptual framework is as follows: a certain industry grows faster in a particular country than others, because this country had dynamic institutional advantage (and comparative) in providing the necessary conditions in the development of the industry.

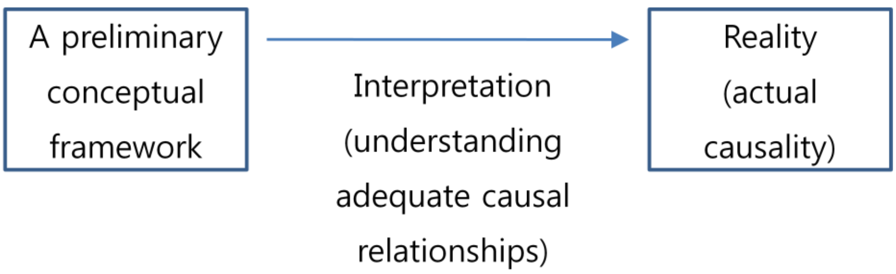
However, a preliminary conceptual framework needs to be modified, because it does not yet reflect the characteristics of the PV industry. After clarifying the object of this research, I shall suggest a more specified conceptual framework with four necessary functions in the development of the c-Si cell industry in the 2000s: demand-pull policy; capital mobilisation; process innovation; and cost reduction.

2. TENSION BETWEEN THEORY AND REALITY

In the late nineteenth century, there was a methodological debate between the German Historical School and the Austrian Theoretical School: the former argued empirical apriorism, while the latter argued a dualism between theory and history (Shin, 1996). In other words, the former tried to reach a general theory through descriptive researches, whereas the latter regarded theory as something separated from historical complexities (Shin, 1996).

Based on this debate, Max Weber (1949) constructed an interpretative sociology: ‘the understanding of social phenomena is attained and enlarged only through an ongoing process of constructing an ideal type and interpreting social phenomena’ (cited in Shin, 1996, p. 42). For Weber, the aim of research is not finding a general theory separated from reality, but understanding the concrete causal relationships in reality (Shin, 1996). Moreover, understanding one causal relationship in reality does not necessarily entail the expectation of similar causal relationship in the future. In line with this, an ideal type can be a preliminary conceptual framework for research (Shin, 1996), thus it is not a theory. In this sense, instead of constructing a theory, some concepts are able to interpret adequate casual relationships in reality. Through these processes, knowledge can be advanced ‘by elucidating the degree of *approximation* to which a particular historical phenomenon can be classified in terms of one or more of these concepts [ideal types]’ (Weber selected in Runciman, 1978 cited in Shin, 1996, p. 42). This explanation is illustrated in Figure III-1.

Figure III-1 Weber’s interpretative sociology



Source: Author

However, I do not fully agree with Weber's thought, especially his thoughts about capitalism, but his idea about 'the formulation of ideal-type constructs' (Giddens, 1971, p.141) gives this study some insights relating to creating a conceptual framework. An ideal type is not ideal in a normative and exemplary sense. Moreover, an ideal type is neither a hypothesis nor description (Giddens, 1971). Instead, an ideal type 'is constructed by the abstraction and combination of an indefinite number of elements' (Giddens, 1971, p. 141). In other words, '[a]ny descriptive concept can be transformed into an ideal type through the abstraction and recombination of certain elements' (Giddens, 1971, p. 142). In this sense, an ideal type lies between empirical descriptions and general theories.

In this point, an ideal type is similar to a conceptual framework. It is necessary to create a conceptual framework for comparative research in order to compare and analyse different cases coherently. The conceptual framework enables this research to go beyond descriptions of cases. However, the aim of introducing the conceptual framework is not building a theory in this research. Explanations using the conceptual framework are somewhere between empirical descriptions and general theories. In this sense, the conceptual framework is a kind of idea-constructs.

From this perspective, firstly, I will explore major concepts which are elements of the conceptual framework. Then, I will suggest a preliminary conceptual framework to understand causal imputation between national political economy and industrial evolution using the concept of institutional advantage.

3. MAJOR CONCEPTS

3.1 Institutions

Before proceeding further, it is necessary to clarify the definition of 'institutions', because it is too broad, and sometimes ambiguous, to apply to the analysis in this study. To begin with, according to the dictionary (Oxford Dictionary, 2004), institution means: '(i) a large organization for the promotion of science, education, etc.; (ii) an established law or custom; and (iii) the action of instituting' (p 736). It defines that a meaning of institution includes an organization.

However, according to Douglass North, '[i]nstitutions are the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction' (1990, p. 3). Moreover, he (1990) suggests a distinction between 'institutions' and 'organisations' as follows:

> A crucial distinction in this study is made between institutions and organizations. […] Conceptually, what must be clearly differentiated are the rules from the players. The purpose of the rules is to define the way the game is played. But the objective of the team within that set of rules is to win the game – by a combination of skills, strategy, and coordination; by fair means and sometimes by foul means (North, 1990, p. 4-5).

From this perspective, the new institutional economics articulates the differences between institutions and organisations as follows:

> Institutions are the written and unwritten rules, norms and constraints that humans devise to reduce uncertainty and control their environment. These include (i) written rules and agreements that govern contractual relations and corporate governance, (ii) constitutions, laws and rules that govern politics, government, finance, and society more broadly, and (iii) unwritten codes of conduct, norms of behaviour, and belief. Organizational arrangements are the different modes of governance that agents implement to support production and exchange. These include (i) markets, firms, and the various combinations of forms that economic actors develop to facilitate transactions and (ii) contractual agreements that provide a framework for organizing activities, as well as (iii) the behavioural traits that underlie the arrangements chosen (Menard and Shirley, 2005, p. 1).

However, some scholars argue that organisations should be considered as institutions[29], attempting to bring together organisational and institutional approaches of innovation (Aoki, 2000; Coriat and Weinstein, 2002). Furthermore, it is argued that disciplinary background relates much to these different definitions (Weiss, 2003). For example, economists such as North and Williamson focus on the rule-bound notion of institution, while political scientists pay more attention to the importance of organisational arrangements (Weiss, 2003).

With regard to the dichotomy between institutions and organizations, the VoC approach, basically, follows North's crucial distinction as follows:

> Following North (1990: 3), we define institutions are a set of rules, formal or informal, that actors generally follow, whether for normative, cognitive, or material reasons, and organizations as durable entities with formally recognized members, whose rules also contribute to the institutions of the political economy (Hall and Soskice, 2001, p. 9).

Thus, the VoC approach identifies main institutions as markets, hierarchies, and non-market mechanisms such as 'powerful business or employer associations, strong trade unions, extensive networks of cross-shareholding, and legal or regulatory systems designed to facilitate information-sharing and collaboration' (Hall and Soskice, 2001, p. 10).

However, from the point of view of the new institutional economics, markets, business associations, trade unions, etc. are categorised into 'organisational arrangements' not 'institutions' as described above. In fact, the VoC approach admits that the distinction is applied to their researches loosely from time to time (Hall and Soskice, 2001, p. 9). Because of this, the concept of institutions seems to include 'organisational arrangements' in the VoC approach.

In this study, I will follow the perspective of the VoC approach because it recognises

[29] Aoki (2000) attempts to categorise main economic institutions as follows: '(i) markets and money; (ii) the legal and political framework of the state; (iii) contracts and (private order) organizations; and (iv) cultural belief and social norms' (cited in Coriat and Weinstein, 2004, p. 327).

the difference between institutions and organisations. Moreover, sometimes it categorises organisational arrangements into institutions, because institutions and organisations contribute to each other within the political economy. Thus, sometimes they are so close to each other, it is not meaningful to distinguish between them strictly. For example, on the one hand, a *chaebol* is a large family firm in Korea, on the other hand, a *chaebol* system can be interpreted as a unique corporate institutional arrangement in Korea. Furthermore, 'organizations provide a structure to human interaction' (North, 1990, p. 4). Thus, organisational arrangements also have a systematic influence on economic actors in a national political economy. Therefore, the concept of institutions covers organisational arrangements explicitly in this research.

3.2 Institutional Advantage

Within the concept of 'comparative institutional advantage', as discussed earlier (II.4.2), I will here investigate the concreteness of institutional advantage.

Alexander Gerschenkron (1962) uses the term 'institutional instruments' in order to explain the industrialisation of Germany and Russia in the nineteenth century. Different from the process of industrialisation in England, industrial investment banking was devised as an institutional instrument for capital mobilisation in the moderately backward country, Germany, while the state played the role of institutional instruments, *acting* as a mobilise of financial resources, in the extremely backward country, Russia (Gerschenkron, 1962).

Unlike England with no established investment banking system at that time, the German investment banking can be interpreted as an 'institutional advantage' which enabled Germany to invest in heavy industry such as the steel industry on a large scale. Thus, Germany could catch up with the English in the steel sector by achieving economies of scale in the nineteenth century (Gerschenkron, 1962).

According to Gerschekron's explanation as above, the investment banking system and the state were unique institutions which were relevant to each nation's industrialisation processes, respectively. Furthermore, it is argued that 'the state-bank-*chaebol* nexus', 'foreign MNCs and government-linked companies', and 'the public enterprises, the *guanxiqiye*, the MNCs, and the SMEs' played the role of institutional instruments in the late industrialisation of Korea, Singapore, and Taiwan, respectively (Shin and Chang, 2003), as discussed earlier (II.2.4.2 p. 26). Thus, institutional advantage can be regarded as differentiated systems at a specific time and in a particular nation. In other words, institutional advantage is concrete only in a specific time and in a particular nation. It is not a general prerequisite for any economy to establish a certain industry. This uniqueness of institutional advantage can be justified by Gerschenkron's perspective and its explanations.

In summary, I attempt to draw on two significant elements of the concept of institutional advantage[30]. Firstly, the institutions of a particular nation can provide an industry with more advantages to grow than that of other nations, as argued by the VoC approach. Secondly, institutional advantage is specific to a certain industry, a certain period and a particular nation, as pointed out by Gerschenkron.

3.3 Necessary Functions in the Development of an Industry

Even though two main elements of institutional advantage may be present, there is a need to introduce lower level analysis to clarify the research. Thus, I will attempt to draw some intermediate concepts which bridge institutional advantage and development of an industry.

A key link appears to rest with necessary functions for creation of an industry. Institutional advantage of a nation may affect the emergence and growth of a certain industry within the country. How does it affect the emergence and growth? Its institutions function better in facilitating the development of the industry than others. Thus, it is very important to identify what functions are required to facilitate the emergence and evolution of the industry.

[30] It is not the aim of this thesis to devise the general definition of 'institutional advantage' which can apply to all the cases, because it is beyond the scope of this thesis and the ability of mine. Thus, I admit the limitation of this thesis with regard to the generalisation of the definition of 'institutional advantage'.

Based on the social system approach (Parsons, 1951), Van de Ven and Garud (2000) suggest three functional subsystems in order to 'provide analytical guidance for investigating the emergence of an industry' (p. 493): an instrumental subsystem, a resource procurement subsystem, and an institutional subsystem. They explain the three subsystems as follows: an instrumental subsystem includes functions such as applied R&D, manufacturing and assembly, and marketing and distribution; a resource procurement subsystem includes basic scientific or technological knowledge, financing and a pool of competent human resources; and an institutional subsystem includes '(i) establishing governance structures and procedures for the overall industry and (ii) legitimising and supporting the industry's domain in relation to other industrial, social, and political systems' (Van de Ven and Garud, 2000, p. 493).

In addition, Jacobbson and Bergek's model (II.3.2.4 p. 35) identifies four features of the formative period of renewable energy industries (Jacobbson and Bergek, 2004).

These two views hold significant implications for understanding the necessary functions of industrial evolution, especially renewable energy industries. In this sense, I use and reorganise their subsystem categorisation and four features of the formative period in order to explain the necessary functions for industrial evolution, with specific regard to the renewable energy industry[31]. Therefore, I suggest the necessary functions to be as follows:

(1) *Market formation*: institutional functions forming initial markets through government policy and legal systems, for example, demand-pull policy

(2) *Resource mobilising*: mobilising financial and competent human resources

(3) *Innovation*: providing basic scientific or technological knowledge, developing and commercializing products and services mainly by applied R&D, manufacturing

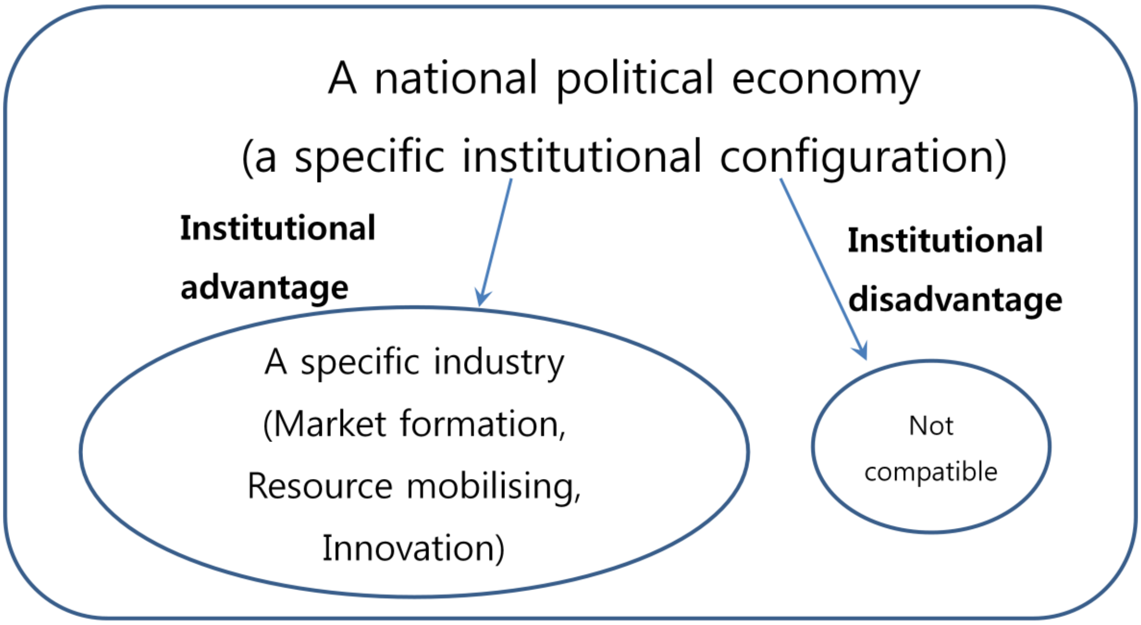
[31] Generally, the renewable energy industry has positive externalities, thus, government subsidy or market creation is very important to overcome the 'market failure'.

4. INTERPRETATIVE CONCEPTUAL FRAMEWORK

4.1 A Preliminary Conceptual Framework

A conceptual framework is a logical abstraction from descriptions and combination of major concepts, lying between empirical descriptions and general theories, as discussed in section 2. The conceptual framework consists of two basic elements: a particular nation and a certain industry. The concepts which bridge between a nation and an industry are institutional advantage and the necessary functions in development of an industry. Because a particular country had an institutional advantage in providing necessary functions for a certain industry, the industry grew faster in this country than other countries. This forms the main argument for this thesis. Thus, I will investigate cases within this conceptual framework, as shown in Figure III-2.

Figure III-2 A preliminary conceptual framework



Source: Author

Firstly, if a nation has an institutional advantage in forming a market for a certain industry, this industry may grow faster in this nation than others. For example, Germany has introduced the feed-in tariff for wind electricity since the 1990s, as a result the wind industry has made a great success in Germany (Jacobsson and Bergek, 2004).

Secondly, if a nation has an institutional advantage in mobilising resources for a certain industry, this industry may be developed further in this nation than others. As Gerschenkron (1962) points out, the investment bank enabled the German iron and steel industry to catch up with the British counterpart in the nineteenth century.

Lastly, if a nation has an institutional advantage in innovation for a certain industry, this industry may be a leading one in the world. For example, as Freeman (1995) points out, mainly due to the differences between national systems of innovation, there were big gaps of economic performance between Japan and the Soviet Union or between East Asian countries and Latin American countries.

This conceptual framework is a kind of lens to look into each case, reality. However, this conceptual framework is a preliminary one, because it does not yet reflect the characteristics of a specific reality, the PV industry. If a preliminary conceptual framework is modified by concrete features of research object, it will become a more specified one. Thus, I will clarify the characteristics of the PV industry and the scope of this research, and then a more specified conceptual framework will be suggested in the next sub-sections.

4.2 Object of Analysis

4.2.1 PV Technology Families

As a whole, there are three technology families in the PV industry[32]: crystalline silicon (c-Si); thin film; and others (Boyle, 1996). Crystalline silicon solar cells accounted for about 90 per cent of the world PV market in 2007[33], thin films and others around 10 and 0.1 per cent, respectively (Photon International, March 2008, cited in EPIA and Greenpeace, 2009). This is shown in Table III-1 and Figure III-3.

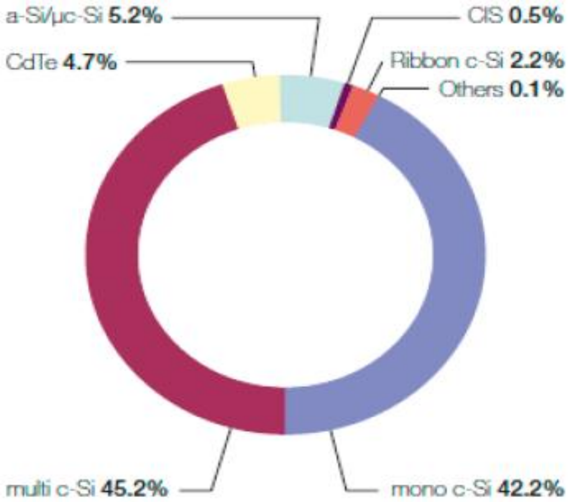
[32] To be more exact, these technology families are not of a PV industry but of a PV cell industry. However, the PV system can be categorised by the technology of PV cell, thus I use the term in this way.
[33] In 2009, c-Si cells accounted for 78 per cent of the PV market (EPIA, 2010).

Table III-1 Three technology families in the PV industry

Technology family	Solar cells	Market share in 2007
Crystalline silicon	Mono c-Si, Multy c-Si, Ribbon c-Si	**89.6 %**
Thin film	Amorphous-Si (a-Si), CdTe, CIS, etc.	10.3 %
others	Multi-junction, Dye sensitized, Organic, etc.	0.1 %

Source: Boyle, 1996

Figure III-3 PV technology market shares in 2007



Source: Photon International, March 2008 cited in EPIA and Greenpeace, 2009, p. 16

I will not deal with all the technology families because their technological bases and stages are different from each other, focussing solely on the crystalline silicon technology because it is the dominant form of technology in the PV market.

4.2.2 PV Technological Trends

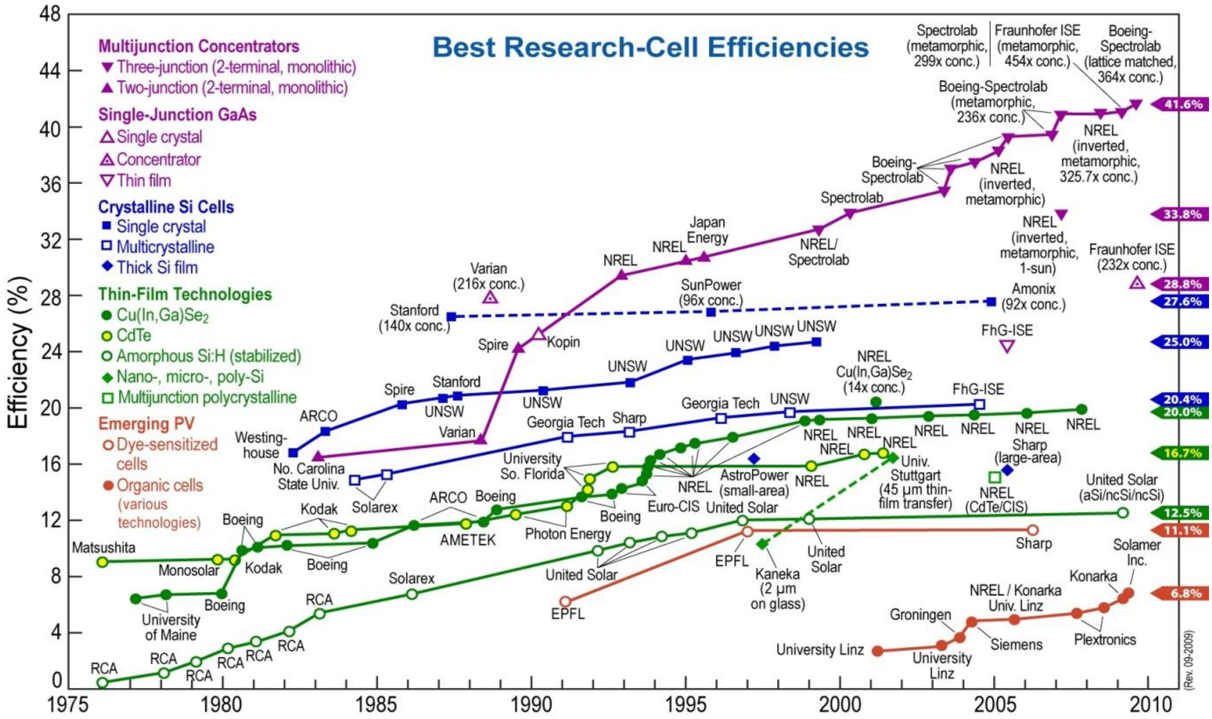
With regard to the period of comparison of the three cases, I will focus on the time since the late 1990s[34], as the new generation of PV firms have appeared since then. Moreover, the PV market has begun to increase substantially in the world market, mainly in the European market, since the late 1990s.

It is said that the crystalline silicon technology has achieved maturity since the late 1990s, as shown in Figure III-4 (blue squares in Figure III-4). According to Utterback's

[34] However, I will deal with the whole period of the PV industry in each case chapter, because the features of the PV industry in the 2000s are closely related to that of the previous PV industry in each country.

ILC theory, after the emergence of a dominant design, technology becomes mature, product innovation decreases while process innovation increases, and cost reduction becomes much more important. In fact, according to interviews, process innovation and cost reduction were ones of the key ways to achieve the global competitiveness of c-Si cell manufacturing in this period.

Figure III-4 Technological trends of PV technology

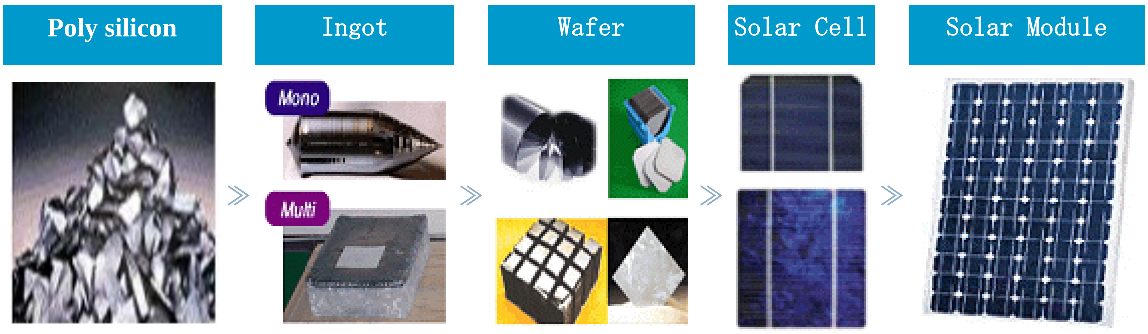


Source: Kurtz, 2009

4.2.3 PV Value Chain

In a crystalline silicon PV industry, as a whole, there are five phases of value chain: poly silicon, ingot, wafer, cell, and module chains, as shown in Figure III-5. Each phase of the value chain has different features as listed in Table III-2. In terms of a minimum efficient scale, the upper stream is in the value chain, the larger it is. Thus, a poly silicon chain is the largest one, while a solar module chain is the smallest one. Moreover, the poly silicon, ingot, wafer and solar cell chains are capital-intensive, whereas a solar module chain is labour-intensive.

Figure III-5 Value chain of crystalline-silicon PV industry



Source: KNREC, 2009

Table III-2 Features of each value chain

		Poly silicon	Ingots	Wafers	**Cells**	Modules
Minimum efficient scale		Very high	high			low
Factor-intensive		Capital-intensive				Labour-intensive
Added value		42 %	13 %	13 %	18 %	14 %
Number of firms in 2010	Korea	3	7	7	11	18
	China				At least 100	At least 300
	Germany				More than 200	

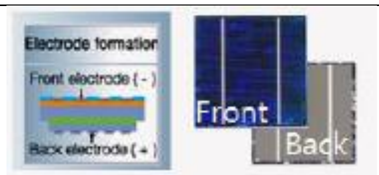
Source: KNREC (2009), ECJRC (2010), BSW (2010)

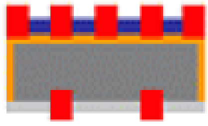
I will focus on the solar cell chain, because it is the heart of technological innovation in the PV industry and it creates a higher value than other chains except the poly silicon chain. The solar cell industry needs a large scale of production capacity in order to achieve economies of scale. In fact, according to interviews, it is said that the basic capacity for economies of scale is a 300MWp of annual production capacity. This requires more than 200 billion KW (approx. 200 million USD) excluding land costs in 2009.

In terms of Pavitt's taxonomy (1984), scale-incentive sectors are characterised as follows: sources of technology are mainly equipment suppliers; users are sensitive to price rather than performance; cost cutting is the main focus in production; and process innovation has more weight than product innovation. In this sense, the taxonomy provides this research with significant insights relevant to the c-Si cell industry in the 2000s. Because cost reduction and process innovation is a main factor of innovation of the c-Si cell industry, it is essential to have a look at the production process of c-Si cells.

The production process of c-Si cells is standardised as a series of eight processes, as listed in Table III-3. According to interviews, some companies add more processes to the standard process in order to increase the efficiency of solar cells. However, it is said that the additional processes are not cost-efficient, thus the standard process is highly dominant in c-Si cell mass production.

Table III-3 Production processes of c-Si cells

Name of process	explanation	illustration
Wafer		
1.Surface etching/Texturing	-Etching saw damage of surface -Texturing the surface in order to receive more sunlight	
2.Phosphor doping/ Diffusion	- P-N junction formation by doping -Thermal treatment for diffusion	
3.Phosphor-silicate glass etching	Remove the phosphor-silicate glass on the surface when doping	
4.Anti-reflex coating	Coating on front surface in order to reduce the reflection of sunlight	
5.Metallization	Silk screen printing for formation of front and back metal electrodes	

6.Firing	Reduce the resistance between metal electrodes and surfaces using thermal treatment	
7.Laser isolation	Detach p-n electrode using laser	
8.Cell test & classification	Classify the cells in terms of efficiency using a sun simulator	

Source: the web site of Millinet Solar (a Korean solar cell company) (http://www.millinetsolar.com/product/product03.asp)

4.3 A Specified Conceptual Framework

Formally, I drew a preliminary conceptual framework on the basis of the literature review in sub-section 4.1. Still, the conceptual framework seems to be abstract, because it was constructed before clarifying the object of this research. Thus, it is necessary to move the conceptual framework closer to the locus of this research.

What I consider it necessary to modify are the essential functions for industrial evolution, because the industry which I will investigate is narrowed down to the c-Si cell industry in the 2000s. Firstly, the market formation of the PV industry is substantially affected by a demand-pull policy such as the feed-in tariff scheme. Thus, market formation can be replaced by the demand-pull policy. Secondly, with regard to resource mobilising, capital is more important than any other resource, considering the capital-intensive characteristic of the industry and economies of scale. Thirdly, process innovation is much more important than product innovation, as pointed out by the ILC theory and Pavitt’s taxonomy. Lastly, it should be noted that cost reduction is one of the main issues of the industry in the context of global competition. Even though cost advantage is one of the main implications of the comparative advantage theory, it is also affected by institutional advantage such as education systems or investment grants.

Therefore, I add this function into a set of specified necessary functions. These modified necessary functions are shown in Table III-4.

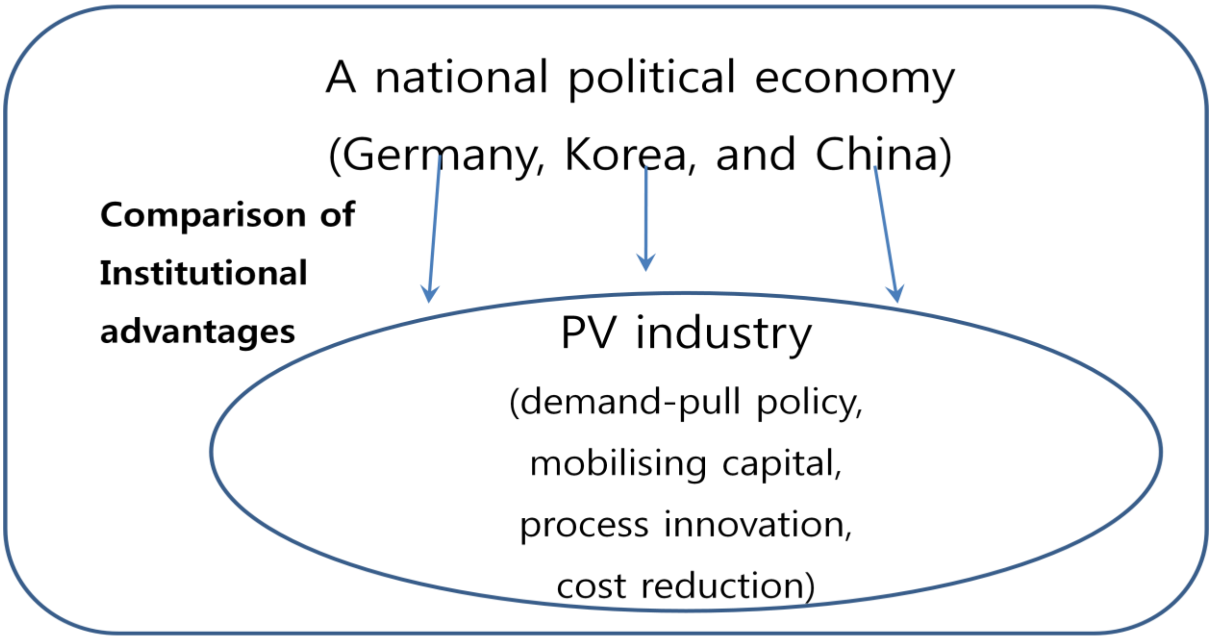
Table III-4 The specified necessary functions[35] for the c-Si cell industry in the 2000s

Necessary functions in a preliminary conceptual framework	Specified necessary functions for c-Si cell industry in the 2000s
Market formation	Demand-pull policy
Resource mobilising	Capital mobilising
Innovation	Process innovation
-	Cost reduction

Source: Author

Thus, the specified conceptual framework is illustrated in Figure III-6. The comparison of the causal relationships between the growth trajectory of the c-Si cell industry in the 2000s and the institutional advantages of Germany, China, and Korea will be examined in terms of the demand-pull policy, capital mobilisation, process innovation, and cost reduction in the chapter on comparison (chapter VIII).

Figure III-6 The specified conceptual framework



Source: Author

[35] Sometimes, the four necessary functions are not clearly separated and are overlapped each other. For example, process innovation and cost reduction are related to each other. However, cheap labour and land costs can be included in the cost reduction function not in the process innovation one.

5. CHAPTER SUMMARY

This chapter has discussed the conceptual framework of this study. Through the literature review in previous chapter, major organising concepts are identified as institutional advantage and necessary functions in development of an industry. Based on these concepts, a preliminary conceptual framework has been constructed with three necessary functions: market formation; resource mobilisation; and innovation.

In order to reflect the features of research object to the conceptual framework, I have clarified the characteristics of the PV industry and narrowed down the PV industry to the c-Si cell industry in the 2000s. Thus, a more specified conceptual framework is suggested with more specified four necessary functions: demand-pull policy; capital mobilisation; process innovation; and cost reduction.

In the empirical chapters (V, VI and VII) and comparison chapter (VIII), this specified conceptual framework will be used as an analysing tool.

CHAPTER IV METHODOLOGY

In this chapter, I shall outline the comparative setting and the data collection and analysis methods that underpin this study. More specifically, I shall explain how I selected the three cases and the unit of comparative analysis. Then, I shall explain the main data collecting methods (archival and documentary sources and interviews) and data analysis methods (a within-case analysis and a cross-case analysis).

1. COMPARATIVE SETTING

1.1 Selection of the Cases

With regard to selection of a case, Eisenhardt (1989) states that:

> The cases may be chosen to replicate previous cases or extend emergent theory, or they may be chosen to fill theoretical categories and provide examples of polar types. While the cases may be chosen randomly, random selection is neither necessary, nor even preferable (Eisenhardt, 1989, p. 537).

In order to choose cases not at random but within a theoretical framework, I will refer back to my initial research question. The question being:

> *What are the main factors underlying the differences between national PV growth trajectories?*

The candidate nations for the selection are the five representative countries whose PV trajectories were illustrated in Figure I-1 (see I.1 p. 1).

These five countries can be classified in two ways: one is by the degree of success of the PV industry; the other is by the degree of PV market formation, which is one of the necessary functions for industry creation that are theorised in the conceptual framework for this thesis. PV production can be a proxy for industry sucess, while demand-pull policy can be a proxy for market formation. These are shown in Table IV-1.

Table IV-1 Categorisation of five countries

		Demand-pull policy		
		Strong	Moderate	Weak
Success of domestic PV industry	Great	**Germany**	-	**China**
	Moderate	**-**	Japan, USA	-
	Small	**Korea**	-	-

Source: Author

In accordance with the polar type selection that Eisenhardt mentions above, firstly, Germany and China can be selected, because they are in contrast to each other in terms of demand-pull policy. The demand-pull policy of Germany has been strong, whereas that of China has been weak, although both of them made a great success of establishing a PV industry. Secondly, Germany and Korea can be chosen, because they are substantially different from each other in terms of the degree of success of their domestic PV industries. The success of the German PV industry has been great, whilst that of Korea has not, nevertheless both of them have implemented a strong demand-pull policy. The three nations, Germany, China and Korea, therefore provide useful comparative cases.

In each case, I will analyse its national political economy and its PV industry since its industrialisation. Thus, the period of the German case which I will examine is the time since the late nineteenth century, that of the Chinese case is since the 1950s, and that of the Korean case is since the 1960s.

1.2 Unit of Comparative Analysis: the c-Si Cell Industry in the 2000s

Clarifying the unit of analysis is one of the fundamental problems in research design (Yin, 2009). Considering the time and budget constraints of this research project, I cannot compare all PV value chains, all PV technologies, and the whole period of PV industries in the three nations. Thus, I need to narrow down the analysis to a comparison of the evolution of the PV industries within these three nations. The object of analysis was discussed in the previous chapter (III.4.2 pp. 50-54). I will focus on the cell value chain, crystalline-silicon cell technology and the period of the 2000s in the comparison chapter (VIII).

2. DATA COLLECTING

In general, a good case study uses multiple sources of evidence because of the advantage of triangulation (Eisenhardt, 1989; Yin, 2009). In this respect, Yin (2009) suggests six sources of evidence in case study research: documents, archival records, interviews, direct observation, participant-observation, and physical artifacts. In line with this, I have made an effort to use as many sources as possible. Given the time and budget constraints of this study, I have relied largely on archival and documentary sources and interviews.

The relationship between archival and documentary sources and interviews is complementary in this study. In general, archival and documentary sources provide stable, exact and broad information but are not associated with the research questions directly, whereas interviews can give accurate information related to the research but can be biased in specific situations (Yin, 2009). Thus, it is important to balance and cross-check between them.

2.1 Archival and Documentary Sources

The main archival and documentary sources of the study are listed in Table IV-2. The important documentary and data sources differ case by case, because well described documents and well-operated databases belong to different kinds of actors according to the specific cases.

Table IV-2 Archival and documentary sources of this thesis

Source	Germany	Korea	China
Government (press release, White paper, data base, reports, etc.)	-BMU (Federal ministry for the Environment, Nature Conservation and Nuclear Safety) -BMWA (Federal Ministry of Economics and Labour) -ECJRC (European Commission Joint Research Centre)	-MER (Ministry of Energy and Resources) -MOCIE (Ministry of Commerce, Industry and Energy) -MKE (Ministry of Knowledge Economy)	-NDRC (National Development and Reform Committee) -NBSC (National Bureau of Statistics of China)
Agencies (data base, reports, etc.)	Solarvalley Mitteldeutschland GmbH	-KNREC (Korea New & Renewable Energy Centre) -KEEI (Korea Energy	REDP (Renewable Energy Development Project) under NDRC

		Economics Institute)	
Industrial association (data base, reports, etc.)	-BSW (German PV Industry Association) -EPIA (European PV Industry Association)	Korea PV Industry Association	Jiangsu Province PV Industry Association
Company	Annual reports, web sites	Web sites	Annual reports, web sites
Magazine	Photon International, Renewable Energy World, Renewable Energy Focus, Solarbuzz		
Conference proceedings	-IEEE Transactions on Electron Devices -EC PV Pilot Projects -Power Sources Symposium	-	SNEC (Shanghai New International Expo Centre) International PV Power Generation Conference
Newspaper	-	-Korea Energy News -Energy & Environment News	China Daily
Similar empirical studies	Lauber and Mez (2004), Jacobbson and Lauber (2006)	none	Marigo (2009)

Source: Author

In the German case, previous studies describe the evolution of the German PV industry very well. Thus, I will refer to many parts of them in this thesis. As for the history of the German PV industry, several conference proceedings are very relevant for the 1970s and 1980s, whereas companies' annual reports provide a good source from the 1990s onwards. With regard to databases, BSW and EPIA have excellent ones.

In the Korean case, few researches have studied the Korean PV industry. Furthermore, few companies' annual reports have been released, because most of the PV cell firms are business parts of the *chaebols*. Thus, I have explored the main government ministries' press releases from 1997 to 2010, White Papers from 1999 to 2009, and newspapers from 2000 to 2011. On the other hand, KNREC (Korea New and Renewable Energy Centre) has a lot of data, for example, the census survey on all PV companies from poly silicon to modules. Thus, I have relied heavily on its reports and data in the research.

In the Chinese case, Marigo's (2009) PhD thesis seems the first in-depth research on China's PV industry and has paved the way for this study to begin research of the Chinese case. REDP's (Renewable Energy Development Project) reports have helpful content to aid understanding of the Chinese PV industry between the 1980s and 1990s. Moreover, companies' annual reports can describe the situation from the 2000s onwards, because most of them are listed in the New York Stock Exchange or the Nasdaq.

2.2 Interviews

In conducting interviews, I have attempted to access insightful information relating to the research questions and to compensate for blank spaces in the archival and documentary research. For example, little information about the Korean PV companies was accessible in the form of documents or archives. Thus, I have relied heavily upon interviews in order to obtain information about the Korean PV firms.

In fieldwork and telephone interviews, I have adopted a semi-structured interview[36] approach because of its flexibility balanced by structure (Gillham, 2005). In other words, the interviews ‘remain open ended and assume a conversational manner’ (Yin, 2009, p. 107), but they also need to follow a certain set of questions related to the research topic.

In detail, the semi-structured interview follows general principles as follows:

- the same questions are asked of all those involved;
- the kind and form of questions go through a process of development to ensure their topic focus;
- to ensure equivalent coverage (with an eye to the subsequent comparative analysis) interviewees are prompted by supplementary questions if they haven’t dealt spontaneously with one of the sub-areas of interest;
- approximately equivalent interview time is allowed in each case (Gillham, 2005, p. 70)

In practice, I made a set of main questions (see Appendix 1) and conducted interviews (see Appendix 2). Table IV-3 provides details of the number of interviews and nature of interviewees for each country.

[36] There are three types of interview: a structured interview, a semi-structured interview, and an unstructured interview; or a survey-type interview, a focused interview, and an in-depth interview (Yin, 2009).

Table IV-3 Interviews in this research

	Number of interviewees			Method (period)	Difficulties → Solutions
	firms	Policy makers	others		
Germany	3	1	4	-First field trip and Intersolar exhibition (May 2009) -second field work (May 2011)	Lack of budget → participation in the UK ESRC project
Korea	16	6	3	Telephone and email (from May 2009 to June 2010)	No time to visit → advantage of government officials
China	9	1	5	Field work (July 2010)	-Contacting interviewees → introduced by the 'Jiangsu PV association' -Language → interpreter

Source: Author

Some difficulties were encountered in carrying out interviews with companies in the three different countries. First of all, it was most difficult to access German companies. For instance, major PV companies such as Q-Cells were very reluctant to meet researchers. However, this did not affect this study much because I was able to access annual reports of these companies. In addition, due to support from the Korean-German Chamber and the UK ESRC (the Economic and Social Research Council) project, I carried out the German field work successfully. In China, language was an issue. Some interviewees did not speak English, thus I was accompanied by an interpreter. Fortunately, Jiangsu PV association introduced me to contact points of major PV companies such as Suntech, Trina Solar and Solarfun. By contrast, it was not difficult to interview Korean PV companies because I was able to take advantage of my connections with government officials. This advantage compensated the lack of archival data of the Korean PV companies. Overall I was able to carry out 48 interviews (Korea: 25, China: 15, and Germany: 8).

3. DATA ANALYSIS

After the collection of data, the next step for the research is ‘how the evidence is to be analyzed’ (Yin, 2009, p. 127). However, there are few fixed formulas for researchers to guide their data analysis. ‘Instead, much depends on an investigator’s own style of rigorous empirical thinking, along with the sufficient presentation of evidence and careful consideration of alternative interpretations’ (Yin, 2009, p. 127). Therefore, I have attempted two types of analyses in order to deal with the research questions comprehensively: a within-case analysis and a cross-case analysis.

Firstly, the within-case analysis is largely composed of two parts. The first part of each case briefly delineates the history of the national political economy. The second part describes the emergence and evolution of the PV industry in the context of the national economy in each case. Through these descriptions, I have made an effort to understand each element in detail and provide an empirical basis for the next analysis, a comparative analysis. In fact, chapter V (the German case), chapter VI (the Chinese case), and chapter VII (the Korean case) follow this type of data analysis. These three chapters are descriptive rather than explanatory[37].

Secondly, a cross-case analysis is a comparative analysis. Based on the descriptive case analysis, I have attempted to explain the casual relationships between institutional advantage and the national growth trajectories of the PV industry. In other words, I will compare the degree of relevance between institutional arrangements of the three countries and four necessary functions for the PV industry: market formation; capital mobilisation; process innovation; and cost reduction. This method of analysis is applied in chapter VIII (Comparison of the three cases). By contrast, with the within-case analysis, this chapter is explanatory rather than descriptive.

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[37] Hart (1998) categorises the goals of research by three research types: exploratory, descriptive, and explanatory researches. The goal of descriptive research is ‘to understand a common or uncommon social phenomenon by observing the detail of the elements that make it a phenomenon in order to provide an empirical basis for valid argument,’ whereas that of explanatory research is ‘to explain the cause or non-occurrence of a phenomenon; to show causal connections and relationships between variables of the types ‘if A then B’; to suggest reasons for events and make recommendations for change’ (Hart, 1998, p. 47).

CHAPTER V PV INDUSTRY IN GERMANY

1. INTRODUCTION

The aim of this chapter is to analyse the evolution of the PV industry in Germany. In particular, I shall outline the evolution of the industry and explain how its evolution reflects four drivers: market formation, capital mobilisation, process innovation, and cost reduction. These drivers are in part a reflection of Germany's underlying social market model of economic development and its underlying political economy. In order to explain the development of the industry, it must therefore be put in the context of the political economy of contemporary Germany. The chapter will therefore start with a discussion of the political economy of Germany and its historical foundations.

Firstly, in section 2, I shall explain in brief the history of the German political economy. In the nineteenth century, the investment banking system and cartels were distinctive characteristics of the industrialisation in Germany. Since then, also, the tradition of cooperation between universities, research institutes, and industries has become strong in Germany. After World War II, the social market economy was established in West Germany. Through economic growth and development, the contemporary German economy can be regarded as a representative model of the coordinated market economy (Hall and Soskice, 2001). Since German unification in 1990, it has affected significantly 'the German model' and the political economy of Germany (Wiesenthal, 2003; Streeck, 2009).

Secondly, in section 3, I shall examine the development of the PV sector in the context of the German political economy. Up until the 1950s, many German scientists were involved in the advance of basic science related to PV technology. Between the 1960s and 1990s, the German PV industry started alongside the emergence of the space-satellite market. After the two oil shocks, many R&D projects and demonstrations for PV systems were supported by public funds. In particular, after the Chernobyl accident, creation of PV markets took place, especially by local activist groups. In the 2000s, the German PV industry took off and grew fast, mainly led by growth of the domestic PV market.

Lastly, in section 4, I shall attempt to show how Germany's institutional configuration and the four main drivers impact on the PV sector: inter-relationships between institutional advantage and the four functions (market formation, capital mobilisation, process innovation, and cost reduction).

2. POLITICAL ECONOMY OF GERMANY

2.1 The Industrial Revolution and between the Two World Wars

In the nineteenth century, the German economy changed from an economy based on agriculture to one dominated by industry, faster than any other economy on the European continent during the time of industrial revolution (Berghahn, 1982). Indeed, industrialisation in Germany was rapidly catching-up with Britain's level of industrialisation. Two main industries were important in Germany's industrialisation at this time: one was the coal industry; the other was the iron and steel industry. In fact, the outputs of coal and steel had risen more than fourfold and tenfold respectively between 1880 and 1913 in Germany, outpacing those of Britain (Berghahn, 1982). Furthermore, new industries such as the chemical and electrical industries accelerated the process of industrialisation in Germany. In fact, the German chemical industry produced three-quarters of the world's synthetic dyes and German electrical products amounted to about half of world's trade in these goods by 1913 (Henderson, 1975).

Many factors had contributed to the success of German industrialisation at this time: the economic and social achievements of Bismarck, the growth of cartels, the influence of credit banks, and scientific and technical progress[38] (Henderson, 1961). Among these, the banks and cartels can be singled out as the most significant institutional factors facilitating German industrialisation. Alexander Gerschenkron (1962) argues that the German bank was the most important institutional instrument of industrialisation in a relatively backward Germany in the nineteenth century, significantly different from the role played by banks in England, as follows:

> Between the English bank essentially designed to serve as a source of short-term capital and a bank designed to finance the long-run investment needs of the economy there was a complete gulf. The German banks, which may be taken as a paragon of the type of the universal bank, successfully combined the basic idea of the crédit mobilier with the short-term activities of commercial banks. […] A German bank, as the saying went,

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[38] The examples of scientific and technical progress were 'Werner von Siemens' electric dynamo, Otto's gas engine, Daimler's petrol engine, Diesel's heavy oil engine, the Haber-Bosch process for the fixation of the nitrogen in the air by electrolysis, and the discovery of alizarin dyes by Caro' (Henderson, 1961, p. 65).

> accompanied an industrial enterprise from the cradle to the grave, from establishment to liquidation throughout all the vicissitudes of its existence. Through the device of formally short-term but in reality long-term current account credits and through development of the institution of the supervisory boards to the position of most powerful organs within corporate organizations, the banks acquired a formidable degree of ascendancy over industrial enterprises, which extended far beyond the sphere of financial control into that of entrepreneurial and managerial decisions (Gerschenkron, 1962, p. 13-14).

The German banks expanded their roles from the short-term activities of commercial banks to the long-term investment of the crédit-mobilier type. They mobilised capital and concentrated it on the main heavy industries such as iron and steel in order to solve the problem of capital scarcity. For example, they took up blocks of shares in order 'to secure the confidence of the investing public,' furthermore, they were 'often represented on the boards of directors of business firms' (Henderson, 1961, p. 62). According to Gerschenkron, the investment banking system was 'perhaps the greatest organizational innovation in the economic history of the century' (Gerschenkron, 1970, p. 102 cited in Shin, 1996). Moreover, during this period numerous mergers took place in the German banking sector. Thus, the six major banks were established by 1908: the Reichsbank, the Deutsche Bank, the Discount Company, the Schaaffhausen Bank, the Darmstadt Bank, and the Commercial Company of Berlin (Henderson, 1961).

Another important institution which played a major role in the catching-up process of German industrialisation was the cartel[39]. At this time, the cartel was a kind of association of firms in cooperation rather than in competition with each other. Sometimes they were developed from previous unions of employers. However, more importantly, the German banks influenced the expansion of the German economy mainly through the establishment of mergers and cartels of various industries (Henderson, 1961). They 'refused to tolerate fratricidal struggles among their children' (Gerschenkron, 1962, p. 15). Rather, 'they were at all times quick to perceive profitable opportunities of cartelization and amalgamation of industrial enterprises (Gerschenkron, 1962, p. 15). At the time, the four main types of cartel agreements were as follows: sharing the market, fixing prices, fixing the total amount of production, and sharing

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[39] The great firms and banks drew more closely together in associations known by various names – 'interest groups', 'pools', 'rings', 'trusts', 'syndicates', and 'cartels' (Henderson, 1975).

profits (Henderson, 1961). Through forming the cartel, German industries could survive within the depression period and expand against cut-throat international competition. In fact, the number of cartels in Germany increased from four in 1865 to nearly four hundred in 1905 (Henderson, 1961).

In the first half of the twentieth century, Germany experienced the two World Wars. In this period, the German economy fluctuated severely between boom and depression and also underwent extreme political and social instability[40]. Although there were many factors which influenced the German political economy during this period, this research will deal with two main features: the uprising of the working class and improvements in science and technological capability. After the Revolutions of 1918 and 1919, the power of the trade union increased and a tradition of cooperation between employers and employees was established as a form of collective bargaining in order to avoid strikes and lock-outs. In fact, the Works' Council Bill, which provided for the employees' representatives to be consulted about working conditions in firms, was ratified in 1920 (Berghahn, 1982). This bill required firms with more than 20 employees to carry out the election of employee's representatives, and these representatives 'had to be consulted about working conditions, proposed redundancies and welfare questions' (Berghahn, 1982, p. 68).

On the other hand, there were big achievements in science and technology before and during the two World Wars[41]. The improvements in science and technological capability in the twentieth century mainly resulted from the establishment of higher education in the nineteenth century. In the late nineteenth century, many technical colleges (*technische hochschule*) were founded, mainly by private companies such as Siemens, Bosch, and Zeiss (Chang, 1998). They conducted a lot of 'applied research' in cooperation with science-based industries, while universities mainly focused on 'pure science' (Tuchman, 1997). Moreover, *Physikalisch-Technische Reichsanstalt* was established as an independent research institute by the government in 1887 in order to

[40] In this period, German society experienced the First World War between 1914 and 1918, the Revolutions of 1918 and 1919, hyperinflation in 1923, the Great Depression in 1933, the Third Reich between 1933 and 1945, and the Second World War between 1939 and 1945 (Berghahn, 1982).

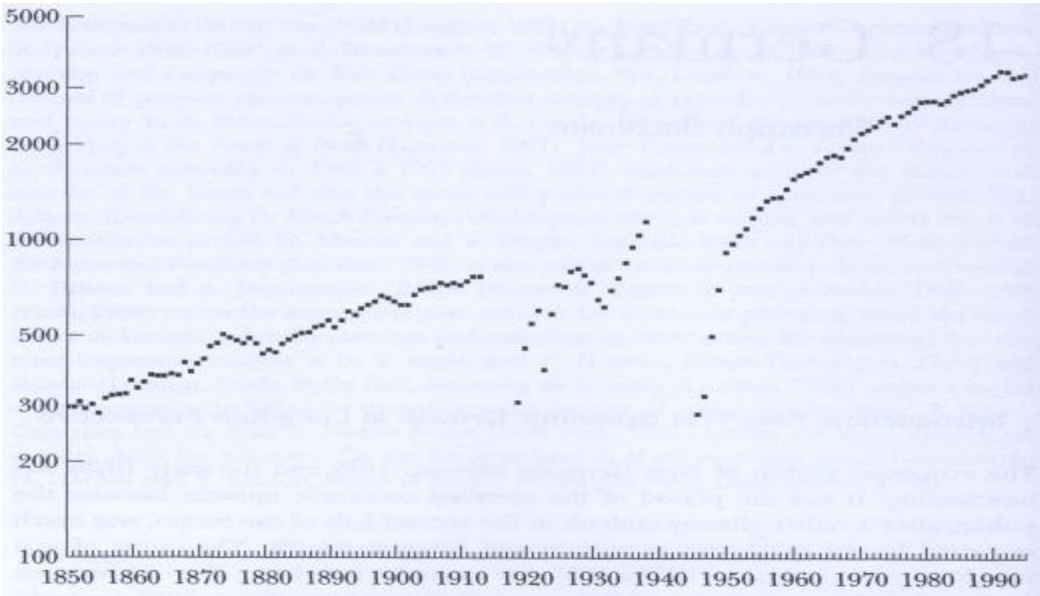
[41] Besides quantum and nuclear physics on which the atomic bomb was based in the Second World War, machine guns, TNT, the submarine, the airplane, and tanks were invented or improved during the First World War (Habeck, 2000).

conduct pure research and satisfy the long-term needs of industry (Tuchman, 1997). From 1912, the Kaiser Wilhelm Society (*Kaiser-Wilhelm-Gesellschaft),* currently the Max Planck Society, was founded which contributed to improvements in modern physics and chemistry (Tuchman, 1997). However, the political situation in Germany was unlikely to contribute further to the development of science and technology under National Socialism and during World War II. From 1933, when National Socialism seized power in Germany, hundreds of scientists emigrated from Germany to foreign countries (Gimbel, 1990). During the Third Reich, German science deteriorated and was destroyed by political ideology and fascism (Tuchman, 1997).

2.2 Social Market Economy: the Second Half of the 20th Century

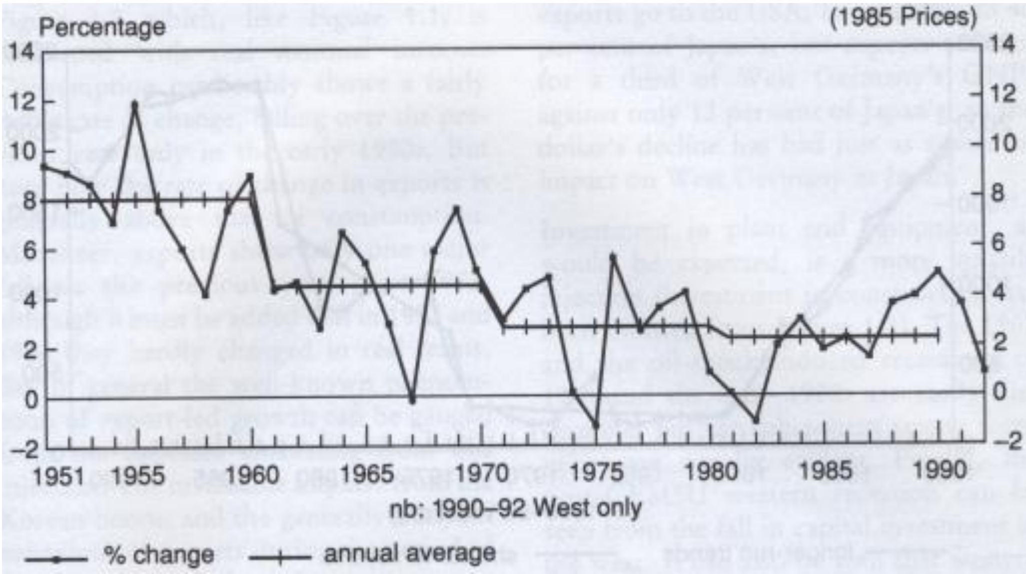
After the Second World War, West Germany recovered very fast and its economic growth was outstanding. As shown in Figure V-1, the trend of post-war economic growth was very steep (Buchheim, 1999). In fact, the average annual growth rate was about 8 per cent in the 1950s, as shown in Figure V-2 (Owen Smith, 1994). After 1973, however, the average annual growth rate declined to 2.74 and 2.21 in the 1970s and 1980s, respectively, as shown in Figure V-2.

Figure V-1 Long-term growth of real GNP per head in (West) Germany, 1850-1995 (unit: Mark, 1913 prices)



Source: Buchheim, 1999, p. 304

Figure V-2 West German growth rate of GNP (Gross National Product)



Source: Owen Smith, 1994, p. 9

There were many factors that contributed to 'the German economic miracle' such as the Currency Reform of 1948, the Marshall Plan and the introduction of Western-style industrial capitalism by Erhard. However, this research will focus on the nature of 'social market economy (*Soziale Marktwirtshaft*)' because most significant peculiarities of the modern German economy stem from the basic philosophy of this concept, in particular, when compared to the Anglo-Saxon economy. Furthermore, the social market economy was the first introduction of a Western-style market mechanism into the German economy which experienced strong government intervention under Bismarck, the Weimar Republic, and the Third Reich and had distinctive economic traditions such as cartels, investment banks, and works councils. Therefore, the social market economy can be interpreted as a complex historical compromise between liberal capitalism, social and Christian democracy, and traditionalism (Streeck, 1997).

The notion of social market economy can be described as being based upon the four principles as follows:

> The first is the definition of competition employed in the model; the second is the appropriate role for state intervention; the third is the place for anti-cyclical measures; while the fourth principle is concerned with the all-important ethical and political aspects of neo-classical liberalism (Denton *et al.* 1968 cited in Owen Smith, 1994, p. 17).

Firstly, the definition of competition is different from the Anglo-Saxon model. It emphasises 'workable competition' rather than 'perfect competition' (Owen Smith, 1994). In other words, 'what matters is not the degree to which perfect competition exists, but the opportunity for the free and untrammelled exercise of competitive energies' (Denton *et al.* 1968 cited in Owen Smith, 1994, p. 17). Secondly, active government interventions are regarded as a necessity in order to facilitate workable competition in the social market economy model, because the market economy is prone to monopolisation. State interventions are needed as a form of anti-trust policies, whereas barriers to competition are seen as being erected by government in the Anglo-Saxon approach (Owen Smith, 1994). Thirdly, a strict control of the money supply was introduced as a stabilisation policy. The German monetary experience such as hyperinflation in 1923 had a strong influence on maintaining price stability. Lastly, according to Müller-Armack, the system provided by the social market economy produced greater 'personal responsibility and individual freedom' (Müller-Armack, 1978). Efficient production and personal freedom were the keystones of a socially balanced order. Thus, not only economic policy but also social policy is an essential part of the principles of social market economy.

Germany's reconstruction and 'the economic miracle' in West Germany were mainly attributable to 'the development of a new style of German economic policy', namely the social market economy (Müller-Armack, 1978, p. 325). This new market economy resulted in a way of thinking that 'it should be possible under the conditions of a free order to find an arrangement satisfying the social needs of our time' (Müller-Armack, 1978, p.325). Thus, the modern German economic order was established on the basis of the concept of the social market economy.

2.3 Contemporary German Economy

2.3.1 Coordinated Market Economy

Modern political economists have focused on understanding institutional similarities and differences in developed countries and the relationships between these institutional differences and economic performance (Hollingsworth *et al.*, 1994; Hall and Soskice, 2001). In particular, the VoC approach attempts to establish a typology in terms of ‘five spheres in which firms must develop relationships to resolve coordination problems’: industrial relations, vocational training and education, corporate governance, inter-firm relations, and internal structure (Hall and Soskice, 2001, p. 6-7). From this perspective, it draws two types of ideal political economy: a liberal market economy (LME) and a coordinated market economy (CME). Firms mainly depend on markets and hierarchies in order to resolve coordination problems with other actors in the former, whereas they depend more heavily on non-market relationships than markets and hierarchies in the latter (Hall and Soskice, 2001).

The German political economy can be identified as one of the most representative economies of the CMEs from the viewpoint of the VoC approach. The distinctive characteristics of the German political economy can be explained as below in accordance with the five spheres. Firstly, in terms of corporate governance and the relationship between firms and external providers of finance, Germany can be described as a ‘stakeholder model’, in contrast to the UK’s ‘shareholder model’[42] (Vitols, 2001). Because the stock market is less influential on corporate governance in the stakeholder model, ‘patient capital’ enables firms to invest in long-term projects and retain a skilled workforce notwithstanding economic downturns in Germany. Moreover, most German firms have a tendency to pursue not only profitability but also market share and employment security (Hall and Soskice, 2001). Secondly, in terms of the internal structure of the firm, stakeholders can participate in major decision making, unlike in Anglo-Saxon firms. Due to the dual board system of German corporate law, employee representatives, as well as major shareholders are included on supervisory boards. So, they are able to share information and participate in the management of the firm. Thus, in Germany, consensus decision-making is a more common way to reach major decisions than unilateral actions by a CEO (Hall and Soskice, 2001). Thirdly, in terms of industrial relations, wage settings are normally achieved through industrial-level

[42] The two models can be explained as follows: ‘the ‘shareholder’ model, in which the maximization of shareholder value is the primary goal of the firm and only shareholders enjoy strong formalised links with top management; and the ‘stakeholder’ model, in which a variety of firm constituencies – including employees, suppliers and customers, and the communities companies are located in – enjoy ‘voice’ in the firm and whose interests are to be balanced against each other in management decision-making’ (Vitols, 2001, p. 337).

bargaining between trade unions and employer associations in order to prevent poaching from a highly skilled labour force. This collective bargaining also helps to limit the inflationary effects of wage settlements. On the other hand, works councils function as complementary institutions at the company level by 'providing employees with security against arbitrary layoffs or changes to their working conditions' (Hall and Soskice, 2001, p. 25). Fourthly, in terms of education and training systems, a publicly subsidized training system tends to provide firms with workers who have highly industry-specific or firm-specific skills. Partly due to these systems, long-term labour contracts are common in Germany. The German employer associations limit circumvention of this system by pressuring major firms to take part in this scheme (Hall and Soskice, 2001). Lastly, in terms of inter-company relations, the German firms tend to focus on product differentiation and niche production rather than direct product competition with other firms within the same industry. With regard to technology transfer, they tend to rely on various institutions such as joint researches and strong industry associations rather than movements of scientific and engineering personnel. Thus, in Germany, closer inter-firm relationships are nurtured in contrast to those within Anglo-Saxon economies (Hall and Soskice, 2001).

The VoC approach is based on the comparative scheme between CMEs and LMEs, it is also important to understand the peculiarity of the German capitalism. Until the 1980s, the German model was able to keep a strong international competitiveness with high-wage and high-skill employment and with low inequality through cooperative upgrading of skills, work organisation, technology and products (Streeck, 1997). In other words, the German industries chose the way of quality-competitive production, ruling out price-competitive production. However, under the conditions of German unification and globalisation, the German model has struggled to keep its distinctiveness as a CME (Streeck, 1997; Vitols, 2001). For instance, due to the recent changes in the institutions involved in corporate governance in Germany within the context of globalisation, the German stakeholder model was adjusted by adding the 'negotiated shareholder value' principle[43] (Vitols, 2001). However, as far as the VoC

[43] The recent changes happened in the areas of company law and financial regulation. Due to these changes, the demands of international investors are highlighted, however, 'consensus on changes is generally reached before implementation through negotiation among top managers with different functional responsibilities and between top managers and employee representatives' (Vitols, 2001, p. 340).

approach is concerned, these institutional changes are not fundamental but incremental because institutions derive from deeply rooted historical traditions (Vitols, 2001).

2.3.2 The Impact of German Unification

When the collapse of communism started in Eastern Europe from 1989, unification between the German Democratic Republic (GDR) and the Federal Republic of Germany (FRG) took place on 3 October 1990 (Wiesenthal, 2003). This unification seems have been beneficial for Germany, but it has negatively affected ‘the German model’ and the political economy of Germany (Wiesenthal, 2003; Streeck, 2009).

The process of German unification happened faster than expected mainly due to the following four reasons: international security considerations of the Kohl government; initial uncertainties about the pathway of unification; the weakness of East German civil society and politics; and Western electoral and political-economic interests (Wiesenthal, 2003). As leading German economists and opposition leaders had warned, the cost of unification was substantial largely due to the rapidity with which it took place. One example was the currency reform in which the East German Mark was exchanged one-to-one with the West German Mark. This reform resulted in economic disaster (Streeck, 2009) and has been evaluated as follows: ‘[t]his amounted to an overnight appreciation of the local currency by about 400 per cent, rendering almost all East German economic activity instantly uncompetitive with western products and services’ (Wiesenthal, 2003, p. 40). As a consequence, many sectors collapsed and unemployment rose dramatically in East Germany. In fact, the unemployment rate was around 20 per cent in the 1990s in East Germany (Wiesenthal, 2003).

In order to compensate for these layoffs, huge transfer payments were provided for the east. In fact, ‘[c]umulative total net financial transfers from the west between 1990 and 2002 reached 800 billion euros’ (Wiesenthal, 2003, p. 42). Moreover, the German government put in place major subsidy programmes to support the economic development of East Germany. Due to the state-subsidised investment, some sectors such as the chemical industry were reconstructed in East Germany (Wiesenthal, 2003). Furthermore, new industries emerged, and one of them was the PV industry. This will be explained in sub-section 3.3.2.5.

Not only western money, but also West German institutions transferred to East Germany: local governments (*Länder*), the education system (primary, secondary, and tertiary education), research institutes such as Fraunhofer institute, and public agencies such as LEG (the state development corporation). In particular, five new *Länders* in East Germany 'had the extraordinary advantage of being able to draw on economic resources from the formerly West German and now all-German public budgets and social security funds' (Wiesenthal, 2003, p. 40). Furthermore, new *Länders* were given more discretion, because 'Germany's 'spatial-federal' system endows its local governments (*Länder*) with considerable autonomy and a prominent role in federal policy implementation' (Anderson, 1996).

On the other hand, German unification changed the status of Germany in European integration. In particular, with regard to European Union Structural and Cohesion Funds, the EU council designated the new *Länder* as the first German objective 1[44] region in 1994 (Anderson, 1996). The regions of objective 1, which are defined as underdeveloped regions, have a priority in terms of the allocation of financial resources. Thus, the designation of the new *Länder* as objective 1 meant that Germany became not only an EU paymaster but also a structural funds recipient. In fact, the new *Länder* received 13.6 billion ECU by allocation of these structural funds between 1994 and 1999 (Wishlade, 1996, p. 49). These funds also encouraged generous investment incentives in East Germany.

[44] 'Objective 1' is an underdeveloped region defined as follows: the region whose '[p]er capita GDP measured in terms of purchasing power parity is less than 75 per cent of the Community average, and other regions whose per capita GDP is close to that of regions under 75 per cent and whose inclusion is justified by special circumstances' (Wishlade, 1996, p.34).

3. EVOLUTION OF THE PV INDUSTRY IN GERMANY

According to industry life cycle (ILC) theories, there are regular patterns in emergence and growth of a new industry. More specifically, Van de Ven and Garud (2000) argue that three periods of an industry's life cycle should be analysed in examining the way in which a new industry emerges and evolves:

> *Initiation* is the time when entrepreneurs decide to form a business venture (if successfully launched will become the birthday of the business unit), and *takeoff* is the time when the unit can exist without the external support of its initiators and continue growing "on its own". The period between initiation and takeoff could be called *startup,* where the new unit must draw its resources, competence, and technology from the founding leaders and external sources in order to develop the proprietary products, create a market niche, and meet the institutional standards established to legitimate the new unit as an ongoing economic enterprise. (Van de Ven and Garud, 2000, p.492)

Moreover, Van de Ven and Garud (2000, p.518) add 'the gestation period' before the initiation phase when they explain the sequence of industry development. The gestation period is the time when basic knowledge is created through basic scientific research (Van de Ven and Garud, 2000). This stage categorization is very significant when analysing the emergence and evolution of the German PV industry, because Germany was one of the first countries to develop its PV industry.

From this perspective, I shall divide the history of the German PV industry into three periods: gestation, initiation and start-up periods. The gestation period started from the 19th century to the 1950s, the initiation period between the 1960s and 1997, the start-up period from 1998, and the take-off period will come when the grid parity is accomplished in Germany or in other critical global markets.

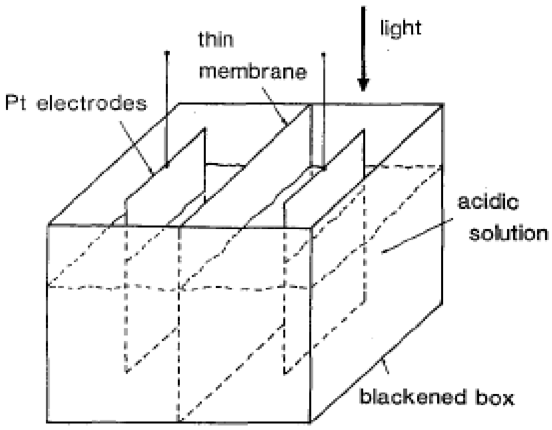
3.1 Gestation Period: 19th Century - 1950s

This sub-section will deal with a relatively long scientific history of the PV cells. Compared with the Chinese and Korean PV industry, the German PV industry was deeply involved in the invention of the early PV cells and advancing basic science relating to PV technology. Thus, the structure of this part is different from other two empirical chapters.

3.1.1 Brief History of the Early PV Cells[45]

When it comes to the history of PV cells, it goes back to Becquerel's discovery of the 'photovoltaic effect'[46] in 1839 (Wolf, 1972; Palz, 1978; Green, 1990; Boyle, 1996; Goetzberger, 2003; Nelson, 2003). Edmond Becquerel, a French physicist, found that a battery's voltage (a wet-cell type) increased when its silver or platinum plates were exposed to light (Boyle, 1996). Figure V-3 illustrates his discovery.

Figure V-3 Diagram of apparatus described by Becquerel (1839)



Source: 'Photovoltaics: Coming of Age' (Green, 1990)

After this discovery, a significant effort was made to advance scientific knowledge

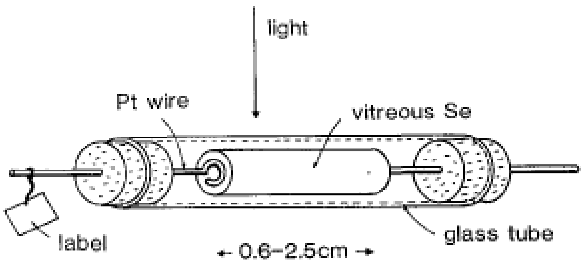
[45] This part covers not only the German experience but also those of the UK, France, and the US, because all these countries were deeply involved in the invention of the early PV cells in the gestation period of the PV industry. Moreover, having a look at the early PV cells is helpful to understand the principle of PV effect and the advance of basic science related to the PV cells.

[46] The basic principle of photovoltaic effect of a silicon solar cell can be explained as follows. 'Light can be considered to consist of a stream of tiny particles of energy, called photons. When photons from light of a suitable wavelength fall within the p-n junction [positive- and negative-type semiconductor], they can transfer their energy to some of the electrons in the material, so 'promoting' them to a higher energy level. Normally, these electrons help to hold the material together by forming so-called 'valence' bonds with adjoining atoms, and cannot move. In their 'excited' state, however, the electrons become free to conduct electric current by moving through the material. In addition, when electrons move they leave behind holes in the material, which can also move' (Boyle, 1996, p. 98).

concerning PV cells within forerunner countries such as the UK, Germany, France, and the US between the late nineteenth century and the early twentieth century (Palz, 1978). At this time, the materials which mainly attracted the attention of scientists and engineers were not silicon but selenium and Cu_2O, because the metallurgy of semiconductor materials had not advanced enough to make silicon mono-crystals of high purity (Palz, 1978).

In 1873, Willoughby Smith, an English electrical engineer, discovered the photoconductivity of the element selenium (Wolf, 1972). In 1876, William Adams, a professor of natural philosophy at King's College in London and his student, Richard Day, observed that selenium produced electricity when it was exposed to light (Wolf, 1972; Nelson, 2003). According to Green (1990), their demonstration paved the way to develop PV cells with solid-state material. Figure V-4 illustrates their PV cell.

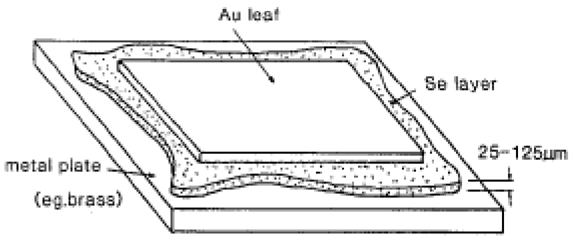
Figure V-4 Sample geometry used by Adams and Day (1876) for the investigation of the photoelectric effects in selenium



Source: 'Photovoltaics: Coming of Age' (Green, 1990)

Also, in 1883, Charles Fritts, an American inventor, devised the first 'thin film' type of solar cell which was formed by coating selenium with an extremely thin layer of gold (Wolf, 1972; Green, 1990; Nelson, 2003). It is illustrated in Figure V-5.

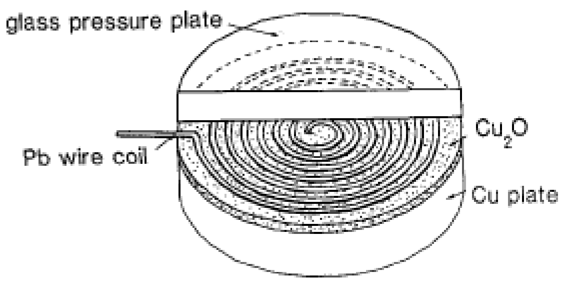
Figure V-5 Thin film selenium cell demonstrated by Fritts in 1883



Source: 'Photovoltaics: Coming of Age' (Green, 1990)

After Wilhelm Hallwachs, a German physicist, observed the photosensitivity of copper cuprous-oxide structures in 1904 (Wolf, 1972), Grondahl, a professor in the US, devised a copper-cuprous oxide photovoltaic cell in 1927, shown in Figure V-6 (Wolf, 1972; Green, 1990).

Figure V-6 Early Grondahl-Geiger copper cuprous oxide photovoltaic cell



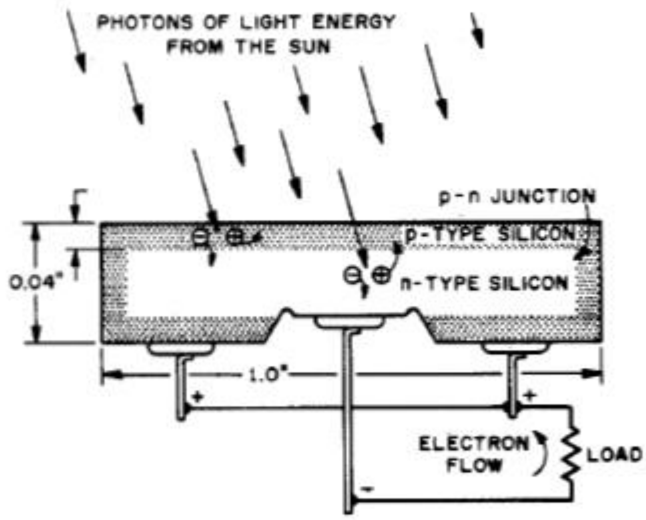
Source: 'Photovoltaics: Coming of Age' (Green, 1990)

In the 1940s and 1950s, silicon solar cell technology made significant progress in the US. Following the development of high purity silicon, in 1941, Russell Ohl, an American engineer, invented a silicon grown-junction photovoltaic cell, even though its energy conversion efficiency[47] was below one per cent (Wolf, 1972; Green, 1990). Finally, in 1954, Pearson, Fuller and Chapin of the Bell Telephone Laboratories invented the first modern silicon solar cell with an efficiency of six per cent (Wolf, 1972; Smits, 1976; Green, 1990; Boyle, 1996; Nelson, 2003). It is shown in Figure V-7. It was

[47] Conversion efficiency means that how much of the incoming insolation can be transferred into electricity. For example, if the conversion efficiency of a solar cell is 20%, it can generate electricity as the same amount of 20% of the incoming solar radiation (Greenpeace and EPIA, 2009).

said that this invention 'opened the first real prospects for power generation using photovoltaics and accordingly aroused considerable interest' (Green, 1990, p. 3). In other words, this silicon-type of solar cell can be interpreted as the emergence of a 'dominant design' among competing types of solar cells from the viewpoint of ILC theory (Utterback, 1994). Evidence of this is that the market-share of silicon solar cell technology has been higher than any other cell technology since their invention.

Figure V-7 Schematic early silicon solar cells



Source: 'History of Silicon Solar Cells' (Smits, 1976)

3.1.2 Advances in Basic Science Relating to PV Technology

According to Pavitt (2005), although science 'remains an insufficient guide to technological practice,' (p. 97) scientific advances can facilitate the opening of new avenues in applied research and provide technical solutions. Basic science relating to PV cell technology, in particular that of physics, advanced much in Germany between the late nineteenth century and the first half of the twentieth century.

There were many examples of scientific advances in Germany relating to the improvement of PV cell technology as follows. In 1874, Ferdinand Braun, a German physicist, discovered 'semiconductor point-contact rectifier effect' which was the first written description of a semiconductor diode (Wolf, 1972). In 1900, Max Planck, a German physicist, identified the quantum nature of light. Prior to his discovery, light was thought to be a continuous electromagnetic wave (Nelson, 2003). Then, in 1905 Albert Einstein explained the 'photoelectric effect', in which electrons are emitted from matter as a consequence of its absorption of energy from light (Nelson, 2003). In 1931, H. Dember, a German professor, discovered electron diffusion theory (Wolf, 1972), and L. Bergmann, a German physicist, reawakened selenium devices which were superior to copper based devices (Green, 1990). Walter Schottky, a German physicist, and Neville Mott, an English physicist, developed the theory of metal-semiconductor barrier layers during the 1930s (Wolf, 1972; Green, 1990; Nelson, 2003).

However, under the Third Reich and after World War II, the political situation in Germany was detrimental to further development of basic science relating to PV cells. Since 1933, when the National Socialists seized power in Germany, hundreds of scientists emigrated from Germany to foreign countries (Gimbel, 1990). Furthermore, after World War II, the 'Paperclip Project, which provided for both military and commercial exploitation of German scientists and technicians in the United States,' (Gimbel, 1990, p. 37) resulted in the emigration of many German scientists and engineers to the US. Because of this evacuation of German scientists and engineers, and the postwar commercial-industrial exploitation programme known as 'the Field Information Agency, Technical (FIAT)[48]' (Gimbel, 1990, p. 60), it inevitably took a relatively long time to resume German research.

Apart from the time before and after the Second World War, why did basic science advance so fast in Germany between the late nineteenth century and the first half of the twentieth century? One of the possible answers can be found in German science and higher education systems such as universities and research institutes, as I describe in subsection 2.1. In the nineteenth century, many technical colleges (*technische hochschule*) and independent research institutes such as the *Physikalisch-Technische Reichsanstalt* were founded (Tuchman, 1997). Furthermore, the Kaiser Wilhelm Society

[48] There are many examples of how companies in the US exploited technology of German companies. One was the Bosch condenser machine. "Reportedly it [the Bosch condenser machine] would save the US condenser industry "millions of dollars a year" by producing condensers that were 50 percent smaller and 40 percent cheaper than those produced in the United States…. Henderson, working as a scientific consultant for FIAT, went to the Robert Bosch, GmbH, facility in Stuttgart, made the investigations, wrote a six-page FIAT report – which the Publication Board eventually sold for 10¢ a copy in the United States – and had one of the twelve-ton machines shipped to the United States to be used as a sample for research and study. The sample machine was allocated by OTS to Western Electric Company and Bell Telephone Laboratories for demonstration to the public" (Gimbel, 1990, pp.103-104).

(*Kaiser-Wilhelm-Gesellschaft)* had a major role in improvements in modern physics and chemistry (Tuchman, 1997). However, during the Third Reich, German science deteriorated and was destroyed (Tuchman, 1997). Meanwhile, in line with the re-establishment of German scientific society, the 'Max Planck Society' (MPS) was founded in 1948 (MPS, 2010). In the next year, 'Fraunhofer Society' was founded (FS, 2010). Both of them have played a major role in the development of basic science and technology of the PV sector in Germany.

In short, it is hard to disagree that Germany was one of the world forerunners during this period in terms of basic science and technological capability relating to PV cells, despite the fact German scientific research of PV cells had difficulty in advancing during and after World War II. These advantages in technological capability in Germany were set to pave the way in developing the German PV industry over the next periods.

3.2 Initiation Period: 1960s – 1997

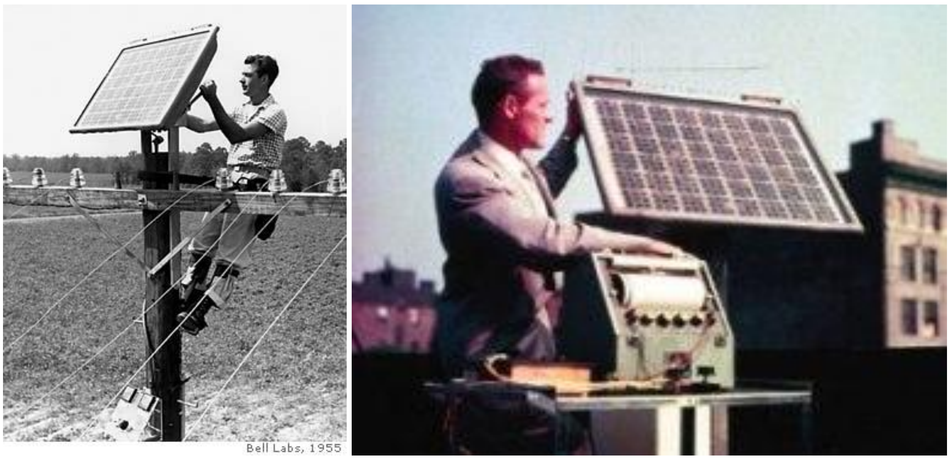
3.2.1 Emergence of the First Generation of PV Firms: 1960s

3.2.1.1 The First PV Market: A Space Satellite Market[49]

After the invention of the silicon solar cell, the Bell Telephone Labs went further with the first demonstration of silicon solar cells as a power source for a rural telephone amplifier in the mid-1950s (Wolf, 1972; Smits, 1976). Figure V-8 shows us the first experimental application. However, the total cost of electricity from a silicon solar cell system was much more expensive than that of conventional power (Wolf, 1972; Smits, 1976). In fact, the price of silicon solar cell was between 100 and 300 USD/Wp[50] in the 1960s (Wolf, 1972). Thus, the ambitious dream of the Bell Telephone Labs failed, and the commercialization of solar cells was regarded as a business of the distant future (Wolf, 1972; Smits, 1976).

[49] This part describes mainly the American PV market because it accounts for almost all the PV market at that time.
[50] The price of silicon solar cells is between 1 and 2 USD/Wp in 2010 (Solarbuzz, 2011).

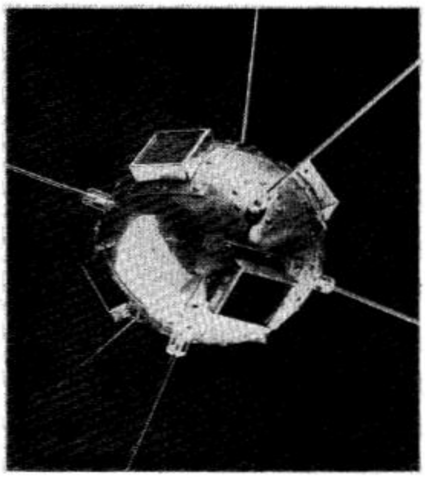
Figure V-8 The first experimental application of a ‘Solar Battery’ in the 1950s



Source: Alcatel-Lucent Bell Labs Website (http://www.alcatel-lucent.com/wps/portal/bell-labs, accessed on 10th February 2010)

Unexpectedly, a new market for solar cells emerged in 1958: a space satellite market. Vanguard I, shown in Figure V-9, which used silicon solar cells to power its back-up transmitter, opened the space age for solar cells in March 1958 (Wolf, 1972; Smits, 1976). Beyond the engineers’ expectations, the solar cells on Vanguard I worked for over six years, compared with the few-weeks lifetime of chemical batteries (Wolf, 1972). Furthermore, because the weight of solar cells was much lighter than any other power source, applying solar cells for space satellites was a tremendous success (Palz, 1978).

Figure V-9 The first use of solar cells for a satellite: Vanguard I



Source: ‘History of Silicon Solar Cells’ (Smits, 1976)

Due to the satellite market, the silicon solar cells market increased rapidly until 1962, reaching 70kWp per year in 1968 (Wolf, 1972). From then, the rate of growth in the silicon solar cells market was sluggish until 1975 (Palz, 1978). Although the size of the satellite market was extremely small from the perspective of current market volume, the satellite market paved the way for commercialization of silicon solar cells.

3.2.1.2 The First Generation of PV Firms

Faced with the US export restrictions on the European Space Agency, ‘Telefunken (AEG-Telefunken)’ and ‘Siemens’ began to develop silicon solar cells in the 1960s (Jacobbson *et al*., 2004). They were the first firms to produce solar cells in Germany. According to a US report intended to help US scientists and engineers become aware of European solar cell activities, they were able to produce silicon solar cells comparable to the United States standards (Curtin and Eakins, 1971). This report described AEG-Telefunken and Siemens in the following terms:

> The AEG-Telefunken cells are manufactured at their modern facility at Heilbronn, near Stuttgart. They have a research and development facility included with their production facility. The research and development facility also has its own pilot production line. Cover slipping and solar panel work is done at the Wedel facility near Hamburg. Both Dr. Richard Epple, Research and Development Director, and Dr. Reinhard Gereth, Senmiconductor Department Head, have had extensive experience in the United States. […] Siemens has manufactured solar cells for the German/French satellite DIAL which was launched in March 1970. They are presently producing cells for the German spacecraft AEROS (Curtin and Eakins, 1971, pp. 595-596).

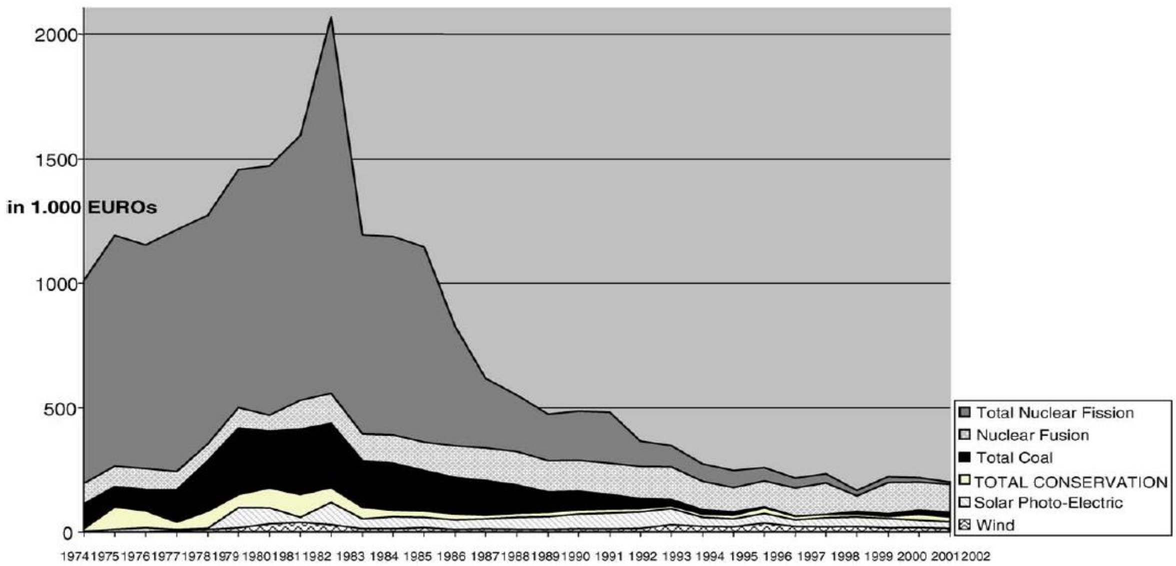
Furthermore, AEG-Telefunken supplied the US and European satellite programmes with more solar cells than other European firms such as SAT of France and Ferranti of the UK (Curtin and Eakins, 1971). In short, German first movers in the PV sector, AEG-Telefunken and Siemens, seemed to start well in view of sales and technological capability during the space age of solar cells.

3.2.2 Research & Development and Demonstrations: 1970s-1980s

3.2.2.1 Oil Shocks and Searching for Alternative Energy Sources

During the 1960s, the price of oil was so cheap that many western European countries, such as Britain, France and West Germany, could replace traditional energy sources such as coal with oil (Sutcliffe, 1996). However, after the first oil shock occurred in 1973 they made an effort to diversify away from oil to other energy sources[51] (Ikenberry, 1986). In Germany, energy diversification mainly led to huge amounts of government funding for research and development of alternative energy sources. Up until the late 1980s, R&D for alternative energy focused more on hard coal and nuclear power than on renewable energy resources, as shown in Figure V-10 (Jacobsson and Lauber, 2006).

Figure V-10 Energy R&D in Germany 1974 – 2002 (prices in 2002)



Source: IEA (2003) Energy Technology R&D Statistics, cited in Jacobsson and Lauber (2006)

Although the size of the R&D fund for renewable energy was relatively small, in 1974

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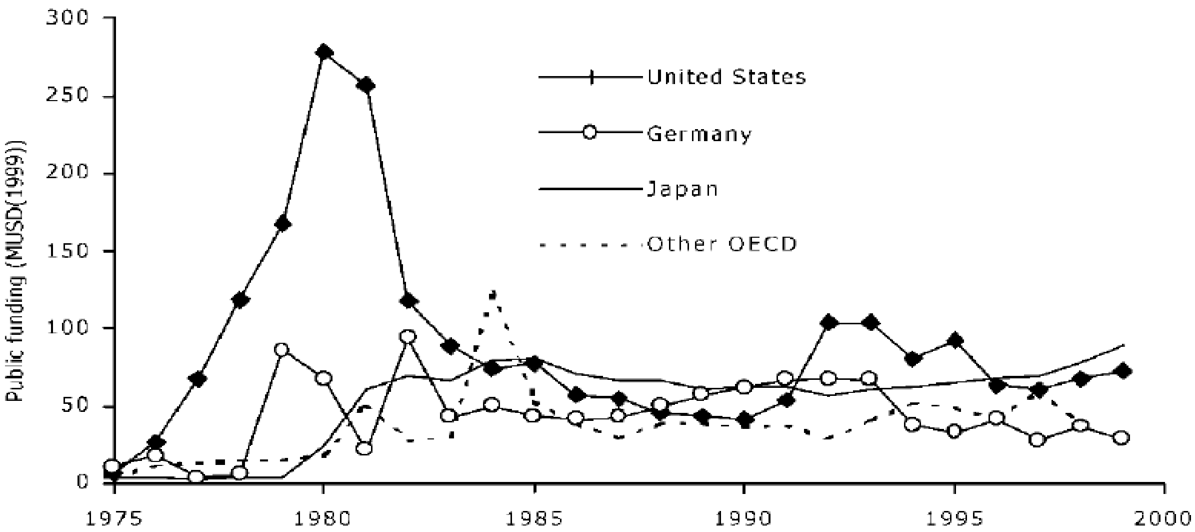
[51] The US, Western European countries and Japan set similar energy security goals as follows: 'diversification of oil sources away from the Middle East, diversification away from oil to other types of energy, and conservation measures to lower absolute levels of energy consumption' (Ikenberry, 1986).

the German government supported R&D for renewable energy for the first time (Lauber and Mez, 2004). Moreover, between 1975 and 1999, the amount invested in German government Research, Development and Demonstration (RDD) programmes for solar cells was not much less than that invested by other leading countries such as the US and Japan, as shown in Figure V-11 (Jacobbson *et al*., 2004).

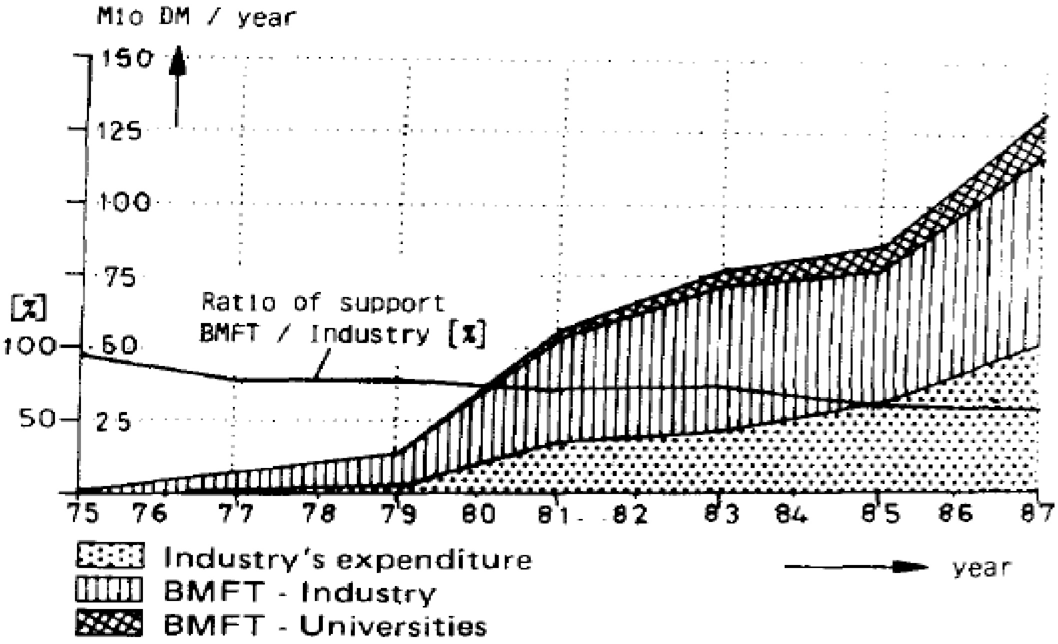
Figure V-11 Public solar cell research, development and demonstration funding in OECD 1975-1999 (in million 1999 US $)



Source: 'Transforming the Energy System – the Evolution of the German Technological System for Solar Cells' (Jacobbson *et al*., 2004)

In addition to government funding, firms' spending on PV R&D was also increased year by year. As shown in Figure V-12, the part financed solely by industry was on the rise, accompanied by the increase in government funding for industrial projects and universities. This indicates that firms began to be interested in the solar sector, recognising potential future markets and investing in the commercialization of solar cells (Pfisterer and Bloss, 1989).

Figure V-12 Industry's expenditure and BMFT support for PV R&D during 1975-1987 (DM values in millions)

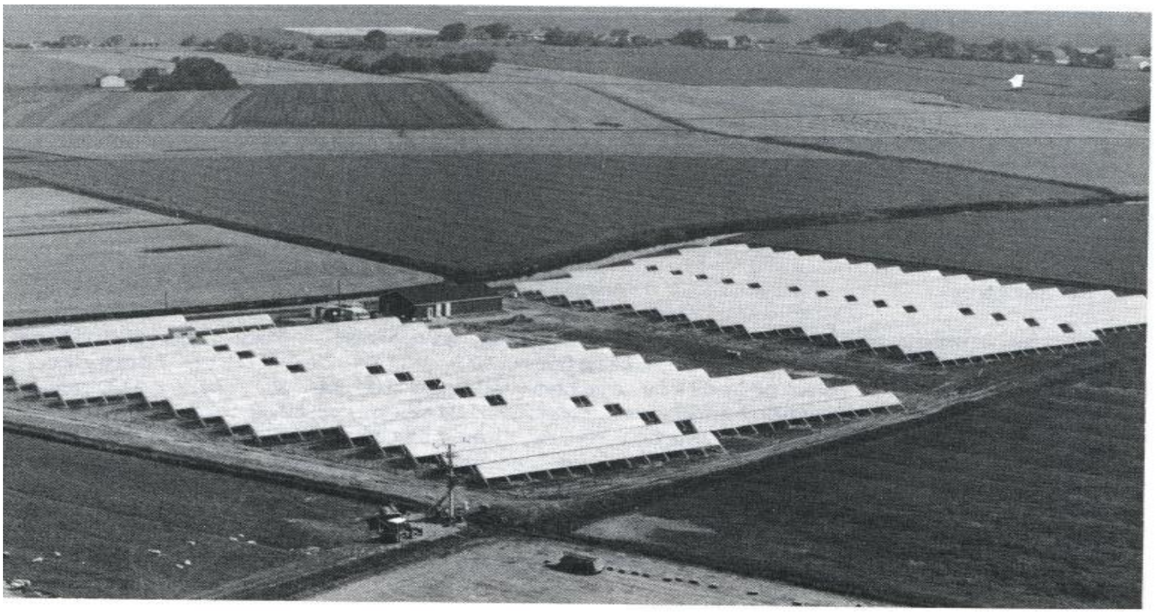


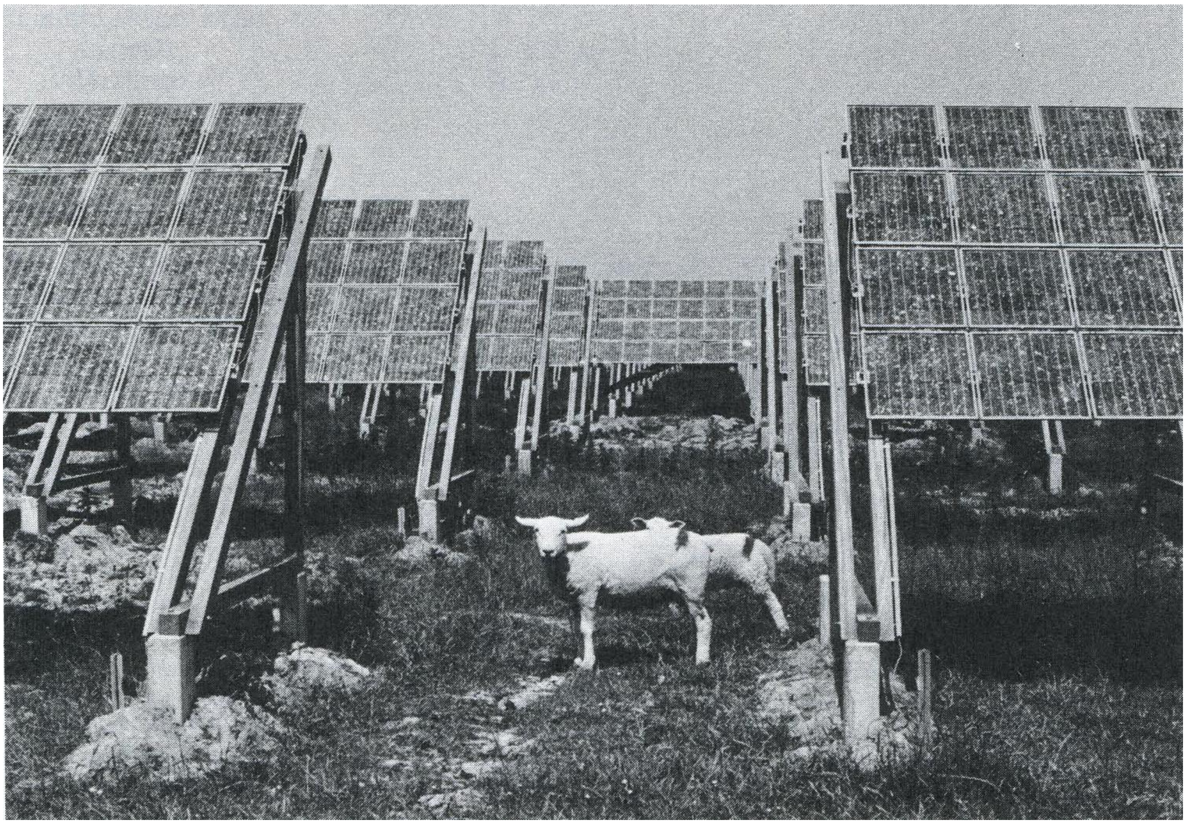
Source: 'Photovoltaic Activities in the Federal Republic of Germany' (Pfisterer and Bloss, 1989)

BMFT: The Federal Ministry for Research and Technology

Furthermore, from 1979, many demonstration programmes were initiated by the Commission of the European Communities (Palz, 1982). At that time, the biggest one was the project of 300kWp PV pilot plant on Pellworm Island, Schleswig-Hostein in Germany (Palz, 1982; Jacobbson *et al.*, 2004). This project was co-funded by the Commission of the European Communities, the federal ministry for research and technology (BMFT) of West Germany and AEG-Telefunken, using AEG-Telefunken's solar cells (Palz, 1982). Figure V-13 shows us pictures of the PV plant of Pellworm. In particular, AEG-Telefunken and Siemens played an active role in supplying solar cells and installation plants not only in Germany but also in other European countries, as shown in Table V-1. Until the mid-1990s, more than 70 demonstration programmes were implemented, accompanied by a two-year monitoring programme (Jacobbson *et al.*, 2004).

Figure V-13 The 300kW PV pilot plant on Pellworm Island





Source: ‘Photovoltaic Power Generation’ (Palz, 1984, p.31 and 34)

Table V-1 PV pilot projects in the European Community in the early 1980s

Site (nation)	Capacity (kW)	Funding bodies (contribution, %)	Project leader
Island of Pellworm (Germany)	300	CEC (41), BMFT (47), AEG-Telefunken (12)	AEG-Telefunken
Vester Bögebjerg near Korsoer (Denmark)	100	CEC (31), BMFT (30), Denmark’s ministry (23),	Siemens

		Siemens (10), etc.	
Kythnos Island (Greece)	100	CEC (16), BMFT (18), Siemens (51), etc.	Siemens
Fota Island, Cork (Ireland)	50	CEC, BMFT, Ireland's ministries, AEG-Telefunken, etc.	AEG-Telefunken and University College Cork
Terschelling Island (Netherlands)	50	CEC (31), BMFT (28), Netherlands' ministry (19), etc.	Holec NV and AEG-Telefunken

Source: 'Photovoltaic Power Generation' (Palz, 1982)

CEC: the Commission of the European Community

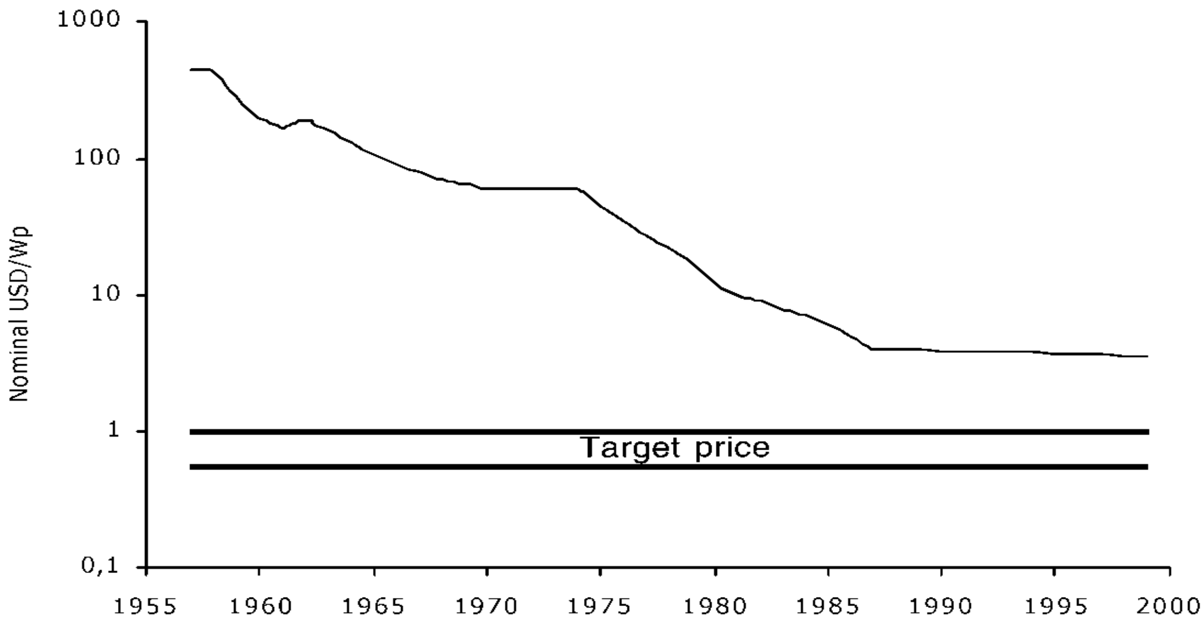
Between 1977 and 1989, overall, 18 universities, 39 firms and 12 research institutes took part in these RDD programmes in Germany (Jacobbson *et al*., 2004). As a result, a great deal of scientific and engineering knowledge and know-how were created and accumulated mainly in the field of crystalline-silicon cells (Jacobbson *et al*., 2004). Moreover, based on the existing high technology of solar cells for space application, the demonstration programmes opened up a new era of large-scale terrestrial use of solar cells beyond the space age. When you compare one terrestrial pilot plant, e.g., 300kWp, with the annual size of the whole space satellite market, e.g., around 100 kWp in the 1970s, in terms of capacity, it is not difficult to understand that the terrestrial market based on large-scale plants can be regarded as the momentum for the evolution of the PV industry. In fact, more solar cells have been sold in the terrestrial market than the space market since 1975 (Palz, 1978). However, at that time, most of the large-scale plants were constructed on islands in order to supply remote areas with electricity and were off-grid generation systems not on-grid ones (Palz, 1982). This means market expansion was limited by geographical and technical factors, as I will discuss in the next sub-section.

3.2.2.2 Problems due to the Lack of PV Markets

During this period, a big demand creator for PV was the large-scale pilot plant programme, as I describe in the previous sub-section (3.2.2.1). Due to these programmes, solar cell markets began to develop separately from the small space satellite market. Still, the market of large-scale pilot plants had inherent limitations for growth. Geographically, these programmes were designed to electrify remote rural areas such as islands and highlands where it was difficult to access the power grid. Unlike developing countries with a huge land mass such as China, there were few rural areas without access to a power grid in Germany at that time. Technically, the solar PV system was an off-grid type which was not able to connect to the power grid directly. Thus, potential in this type of market for solar cells was not substantial.

Another significant problem to solve in order to create PV markets was the higher price of PV electricity than those of other energy sources. Due to the effort of engineers and manufacturers, the price of silicon modules dropped from several hundred USD/Wp in the 1960s to below 20 USD/Wp in the 1970s and to below 10 USD/Wp in the 1980s, as shown in Figure V-14 (Jacobbson *et al.,* 2004). These improvements were remarkable successes in terms of cost reduction in the PV system. However, the price of solar PV electricity was still more than ten times as high as that of coal electricity at that time.

Figure V-14 Silicon solar module price



Source: 'Transforming the Energy System – the Evolution of the German Technological System for Solar Cells' (Jacobbson *et al*., 2004)

As a consequence, the growth of the PV market was retarded in this period. In fact, the accumulated PV installed reached only 1.5 MWp in Germany by 1990 (Jacobbson *et al*., 2004). Furthermore, the big boost for the large-scale power plants ended with the changes of support policies by the Reagan administration in the USA. Thus, the rate of growth of the global PV market was only 13% per year in the period from 1983 to 1996 (Jacobbson *et al*., 2004). At this time, the commercial off-grid power market was the only dominant form of the PV market, especially in developing countries such as China.

3.2.3 Attempts to Create PV Markets: 1980s-1990s

3.2.3.1 The Chernobyl Accident and Environmental Movements

After the first oil shock in 1973, a few solar energy organisations appeared in Germany. The German Society for Solar Energy (DGS) and the German Solar Energy Industries Associations (BSW: *Bundesverband Solarwirtschaft*) were ones of these organisations (Jacobbson *et al*., 2004). At that time, as I mention in sub-section 3.2.2.1, the R&D funding available for nuclear energy was much greater than the funding available for renewable energy. Before 1986, public opinion in Germany was divided on the question of nuclear power. However, the Chernobyl nuclear accident had a deep impact on the whole of German society, especially on the parts related to the transformation of the energy system. Firstly, after it happened in 1986, opposition to nuclear power increased and reached over 70 per cent of public opinion by 1988 (Lauber and Mez, 2004). Secondly, some political parties, in particular, the social democrats (SPD) and the Green party, began to commit themselves to phasing out nuclear power[52] (Lauber and Mez, 2004). Lastly, more active and powerful organisations for solar PV energy were founded: *Förderverein Solarenergie* (Solar Promotion Association) and Eurosolar[53]. The former, a kind of non-government organisation, developed the concept of 'cost covering payment' for electricity generated by renewable energy technology, which was later applied to various feed-in laws (Jacobbson *et al*., 2004). The latter was the first organisation, a group of politicians, which promoted a vision of a 100 per cent renewable energy supply (Wüstenhagen and Bilharz, 2006).

[52] When the so-called red-green coalition became the ruling party in 1998, they legislated the phasing out law.

[53] Eurosolar 'is an organization for campaigning *within* the political structure in contrast to the conventional pressure groups that lobby politicians. Eurosolar has 65 members from all political parties within the German Parliament, excluding Liberals, and 800 politicians at all levels in Germany (Federal, *Ländern*, local)' (Jacobbson *et al*., 2004, p. 15).

3.2.3.2 1,000 Roof Programme, Feed-in Law and the Aachen Model

In the theoretical chapter above, the creation of markets was identified as one of the most important drivers of institutional advantage for the development of the PV industry. Responding to increasing interest in solar energy, three significant attempts aimed at creating solar PV markets were initiated in Germany: the 1,000 roof programme, the Electricity Feed-in Law of 1990, and local-level activities such as the Aachen model. Firstly, in 1989 the German Federal Ministry of Research launched market creation programmes for renewable energy, specifically, a 100 MWp wind programme and the 1,000 roof programme (Lauber and Mez, 2004). The 1,000 roof programme was a success and led to the installation of 2,250 grid-connected roof-mounted installations with a capacity of 5.3 MWp by 1993 (Lauber and Mez, 2004). In relation to solar technology, this on-grid system led to the development of new inverters which related directly to the development for the standard and conditions of feeding decentralized power into the network grid (Jacobbson *et al*., 2004). In terms of potential market, this programme achieved another big step forward moving from an off-grid solar power system to an on-grid one. The on-grid system had a wider market potential than the off-grid one, however, the size of market created by this programme was still not enough to induce new investment in the PV industry.

Secondly, *Förderverein Solarenergie* (Solar Promotion Association) and Eurosolar suggested the concept of a ‘cost covering feed-in law’ in 1989. This suggestion was accepted by all parliamentary parties and became ‘the Electricity Feed-in Law of 1990’ [54] (Lauber and Mez, 2004). The law required electric utilities to connect renewable energy generators to the grid and to buy the electricity at rates of 65 to 90 percent of the average tariff for final customers. This was the most significant institutional change in the history of renewable energy in Germany. In fact, the wind energy market exploded in Germany due to this law. However, according to this law, solar PV electricity was able to sell to electric utilities at nearly 17 pfennig[55] (approx. 9

[54] The passing of this law was not difficult at that time. The majority of CDU members agreed because the law was supported by 3,500 owners of small-scale hydro power plants which were politically conservative. Within the German parliament, 15–20 politicians from the CDU, SPD and the Greens, organized within the Eurosolar Parliament Group, worked for the acceptance of the law (Jacobbson *et al*., 2004).

[55] 100 pfennigs = 1 DM (0.51 Euro).

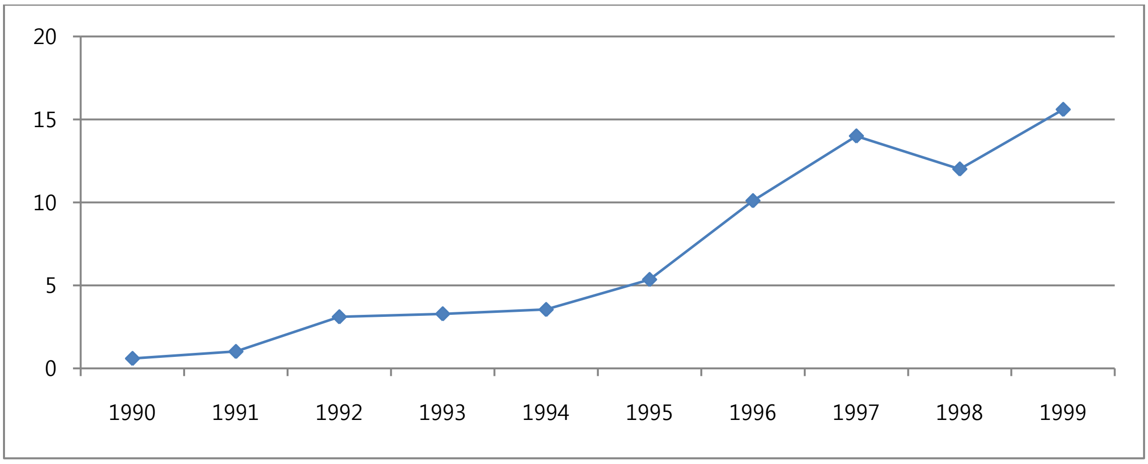
Euro cents) per kWh (Lauber and Mez, 2004). This price level for PV electricity was too low to cover costs. Thus, the Electricity Feed-in Law of 1990 did not play any role in market creation in the PV sector at this time.

In other words, neither the 1,000 roof programme nor the feed-in law of 1990 contributed enough to help the German PV industry survive in the 1990s. Rather, local-level activities were more helpful to its survival. Local solar activists petitioned local governments to impose ‘cost covering contracts’ with renewable generators on the municipal utilities. This movement, known as the Aachen model because it started first in Aachen city, spread over dozens of cities in Germany (Lauber and Mez, 2004). Additional help came from the *Länders* (states) governments in the form of market introduction programmes, subsidising solar installations, and green pricing (Lauber and Mez, 2004; Jacobbson *et al*., 2004). Due to these local-level initiatives, the German PV market continued to grow throughout the 1990s, even though the 1,000 roof programme ended in 1993 (Lauber and Mez, 2004).

3.2.3.3 Merger and Acquisition of the First Generation of PV Firms

Due to the 1,000 roof programme and local-level activities, the domestic PV market grew steadily during the 1990s. As shown in Figure V-15, annual demand for PV was over 10 MWp in the late 1990s (Jacobbson *et al*., 2004). Considering that the whole capacity of the 1,000 roof programme was 5.3 MWp, this growth of the German PV market was remarkable.

Figure V-15 Annual PV capacity installed in Germany (unit: MWp)



Source: Jacobbson *et al*., 2004

Due to the growth of the PV market in the 1990s, the first generation of PV firms became more active than before. Firstly, they took over the US PV firms which had state-of-the-art PV technology. In 1990, Siemens acquired ARCO Solar, a US PV firm, which had started in 1977 and was one of the largest silicon solar cell manufacturers at that time (Jacobbson *et al*., 2004). In 1994, ASE (Applied Solar Energy: *Angewandte Solarenergie*) was set up by NUKEM and Daimler-Benz Aerospace. And then, ASE acquired Mobil Solar, a US PV firm which had developed the EFG (Edge-defined Film -fed Growth) silicon ribbon technology[56] in 1973 (Jacobbson *et al*., 2004). These seem to be very ambitious M&As in an attempt to become world leading solar cell companies. Milestones of each firm are shown briefly in Table V-2.

Table V-2 M&As in the German PV sector in the 1990s

	1973	1979	1980	1982	1990	1994	1998	1999	2002
Siemens	ARCO Solar was founded.		ARCO Solar became first company to produce more than 1 MW of PV modules in one year.	ARCO Solar commissioned world's first 1 MW grid-connected PV installation.	Siemens acquired ARCO Solar, forming Siemens Solar.		Shell invested a 9.5MW factory in Germany.		Shell acquired Siemens Solar, creating Shell Solar.
ASE	Mobil Tyco Solar Energy developed the EFG solar cell.	NUKEM developed a thin-layer compound semi-conductor.				NUKEM and Daimler-Benz Aerospace set up ASE. ASE bought Mobil Solar.	ASE invested a 20MW factory in Germany.	RWE acquired ASE.	

Source: Websites of Schott Solar and SolarWorld

Secondly, aggressive investments in mass production took place in Germany in the late 1990s. Expecting the realization of a potential domestic PV market, ASE constructed a new factory with a annual production capacity of 20 MWp in Germany, which started to produce in 1998 (Lauber and Mez, 2004). Similarly, Royal Dutch Shell entered into the German solar cell industry with a 9.5 MWp plant (Lauber and Mez, 2004). Partly, these investments must have been induced by political promises and implicit incentives

[56] Instead of sawing silicon ingots with wire saws to make wafers as in the conventional method, two strings are used to grow silicon ribbon directly from molten silicon. Like a film of soapy liquid forms on a bubble blower, a silicon ribbon forms between the strings. The silicon crystallizes between the strings and is then cut into wafers with a laser. ASE commercialized this technology successfully using an octagon shape crystal growth method in 2001 (Schmidt et al., 2002).

(Jacobbson *et al*., 2004). However, the volume of two large manufacturers was too big to be satisfied with the actual domestic market size. Thus, they had difficulty in running factories because of large losses (Jacobbson *et al*., 2004). In other words, although the domestic PV market was growing, the size of it was still not sufficient to be economically viable. Finally, in the 2000s they were taken over by RWE Schott Solar and SolarWorld, the so-called new generation of PV firms. I shall describe this in detail in the next section.

3.3 Start-up Period: 1998 – 2000s

3.3.1 Market Explosion: the Great Change in the Feed-in Tariff

3.3.1.1 Political Challenge to the Feed-in Tariff

Since the Electricity Feed-in Law of 1990, opposition to the feed-in scheme had been raised by electric utilities with their invested interests in the incumbent technologies such as coal and nuclear, as they had to pay more and more money to renewable electricity generators (Jacobbson *et al*., 2004; Lauber and Mez, 2004). The opposition was supported directly and indirectly by the utilities association VDEW (German Electricity Association), the Ministry of Economic Affairs, and some of CDU(Christian Democratic Union of Germany)/CSU (Christian Social Union) parliamentary members. At first, in 1996, VDEW complained to DG Competition (the subdivision of the European Commission which looks after fair competition) that the feed-in law violated state-aid rules (Jacobsson and Lauber, 2006). DG Competition pronounced that feed-in rates should be reduced along with costs, addressing particularly wind power. Encouraged by this support, the Ministry of Economic Affairs proposed an amendment that decreased the rates (Jacobsson and Lauber, 2006).

However, the government proposal provoked a repetition of large scale demonstrations that advocated renewable energy. In 1997, environmental organizations, solar and wind industry associations, metal workers trade union IG Metall, farmer groups and church groups protested against the government's attempt to change the feed-in rates. In addition, the Association of Investment Goods Industry and VDMA (German

Engineering Federation) joined the opposition (Jacobsson and Lauber, 2006). Finally, the government proposal was rejected by a narrow vote of 8 to 7 in a select committee in the Parliament (*Bundestag*), and it seems that not only the Green and SPD members but also some CDU and CSU members voted against the reduced rates (Jacobsson and Lauber, 2006). This meant that renewable energy overcame the political challenge and won substantial legitimacy in Germany.

3.3.1.2 The Great Change: Breakthrough for PV

Whereas the wind market had increased substantially in Germany since the Electricity Feed-in Law of 1990, the solar PV market was still not stimulated by the feed-in law mainly due to the unrealistic feed-in rate, as I describe above in sub-section 3.2.3.1. This situation did not change until the Social Democratic-Green coalition became the ruling party. There were some attempts to boost the PV market in the 1990s. After the end of the 1,000 roof programme, Eurosolar proposed a 100,000 roof programme in 1993 in order to help the German PV industry to survive. However, this proposition was not supported by the ruling coalition, the Conservative-Liberal government, so was not adopted at that time (Jacobsson and Lauber, 2006). After the major investments of ASE and Shell in 1998, lobbying by the solar cell industry also intensified (Jacobsson and Lauber, 2006).

In 1998, the Social Democratic-Green coalition took over the government from the Conservative-Liberal coalition. Firstly, it started the 100,000 roof programme in January 1999, providing subsidies in the form of low interest loans to investors (Jacobsson and Lauber, 2006). Secondly and more importantly, the revision of the feed-in law was started later in 1999. During this process, the Ministry of Economic Affairs repeatedly delayed and diluted these efforts and big electric utilities opposed. However, the Social Democratic-Green coalition, the majority of the Parliament, finally adopted the Renewable Energy Source Law (*Erneuerbare Energien Gesetz*: EEG) in March 2000, supported by environmental organizations and industry associations (Jacobsson and Lauber, 2006).

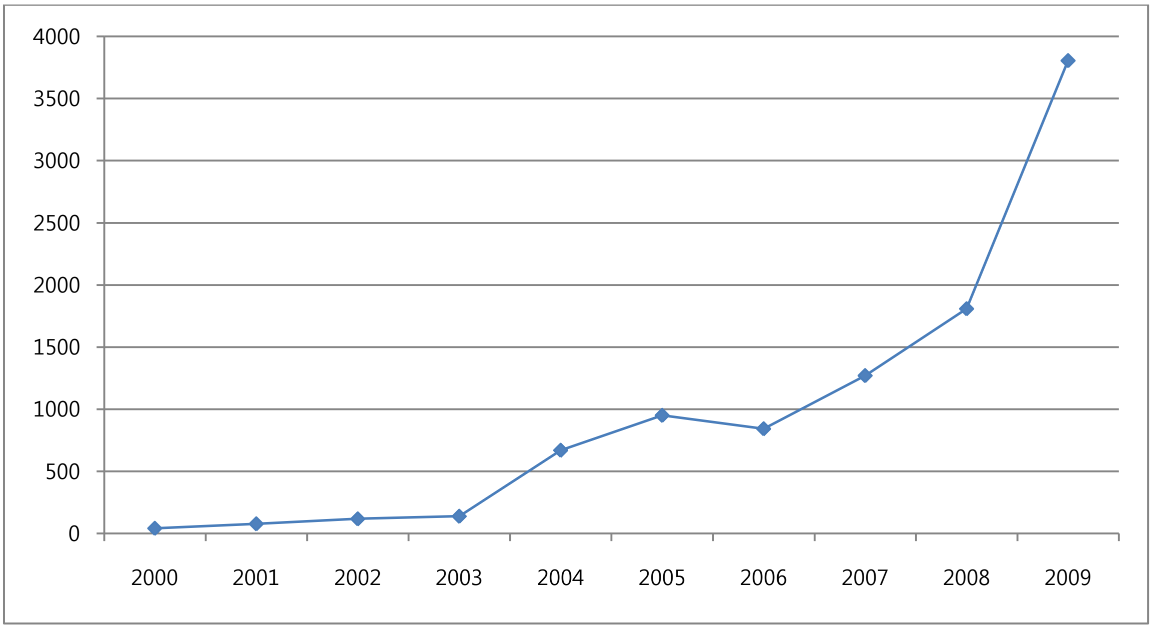
This was the most significant institutional change affecting market creation for the PV industry. Firstly, the rate of PV was increased from 17 to 99 pfennig (approx. 50 Euro cents) a level which could cover the cost of PV electricity (Jacobsson and Lauber, 2006). This was a tremendous increase, considering the new rate was over five times as high as the previous one. Secondly, the new rate would be guaranteed for 20 years (Jacobsson and Lauber, 2006). It is necessary to guarantee long-term rate, considering the turn-over time from the initial investment in PV systems which are capital-intensive. These two main features of the change were enough to attract much attention from investors in PV systems. Therefore, the German PV markets have begun to take off since the adoption of the EEG, I shall describe this in detail in the next sub-section (3.3.1.3).

Another important issue that should be noted is the attitude towards nuclear power as it will determine to what extent a nation will focus on renewable energy sources. If you abandon nuclear power, there is only one alternative energy option which is to develop renewable energy. Since the Chernobyl accident in 1986, opposition to nuclear power increased as I describe earlier in sub-section 3.2.3.1. After the emergence of the Red-Green coalition, the Nuclear Energy Phase-Out Act was adopted in 2002 (Lauber and Mez, 2004). Thus, this act accelerated German society to develop renewable energy sources.

3.3.1.3 Explosion of the PV Market

After the revision of the feed-in tariff of 2000 (EEG), the German PV market exploded, as shown in Figure V-16. The average annual growth rate of the market was around 100 per cent except in 2006, as shown in Table V-3. When you consider that the German PV industry was deeply involved in the revision of feed-in tariff, it is not difficult to understand that the German PV industry perceived the importance of the growth of domestic PV markets. That is to say, due to this significant change of the feed-in tariff the PV market increased rapidly in Germany. As a consequence, the German PV industry benefitted from the fastest growing PV market. This is the reason why the German PV industry participated heavily in the process of revision of the law.

Figure V-16 The German PV market in the 2000s (unit: MWp)



Source: ‘Statistical data on the German PV industry’ (BSW, 2010)

Table V-3 Annual PV installed and growth rate in Germany in the 2000s (unit: MWp)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Annual PV installed	42	78	118	139	670	951	843	1,271	1,809	3,806
Growth rate (%)	163	86	51	18	382	42	-11	51	42	110

Source: ‘Statistical data on the German PV industry’ (BSW, 2010)

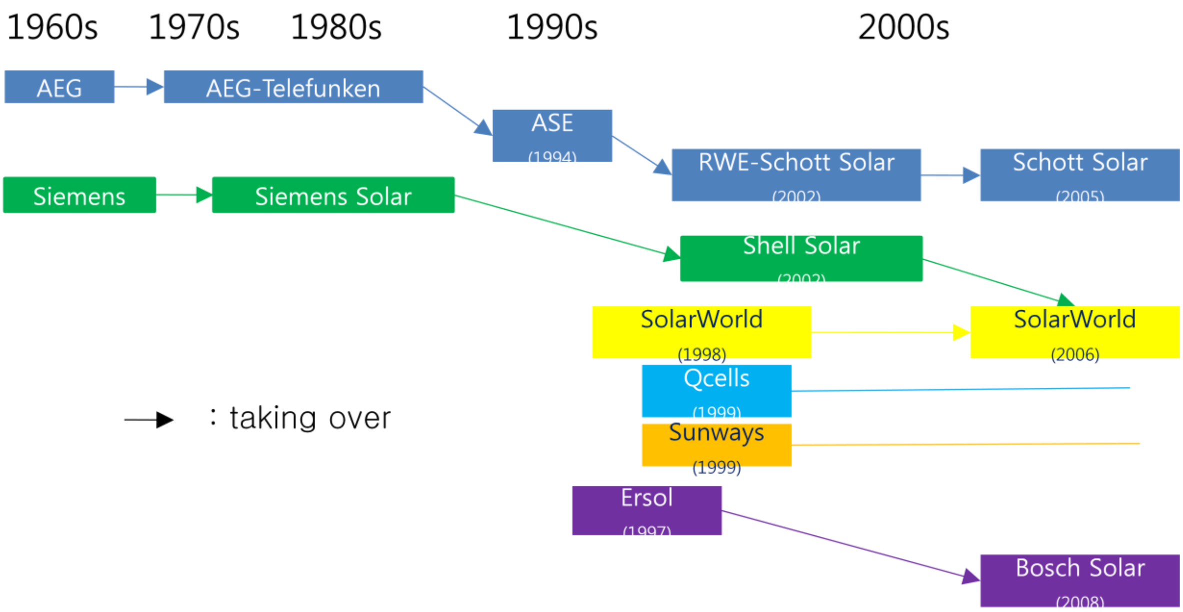
3.3.2 Emergence of the New Generation of PV Firms

3.3.2.1 Entry of New PV Firms

There were two main PV cell firms in Germany until the late 1990s: ASE and Siemens Solar. As the PV support policy became stronger and the PV market grew, however, new PV cell companies have appeared in the German PV industry since the late 1990s, such as Ersol, SolarWorld, Q-Cells, and Sunways, as shown in Figure V-17. Schott group, one of the biggest glass manufacturers, participated in the PV industry in 2002. Siemens Solar was taken over by Shell Solar in 2002, and finally, Shell Solar was acquired by SolarWorld in 2006. In addition, Bosch group entered into the PV sector by acquisition of Ersol Solar in 2008. These entries and acquisitions are illustrated in

Figure V-17.

Figure V-17 Main PV cell companies in Germany



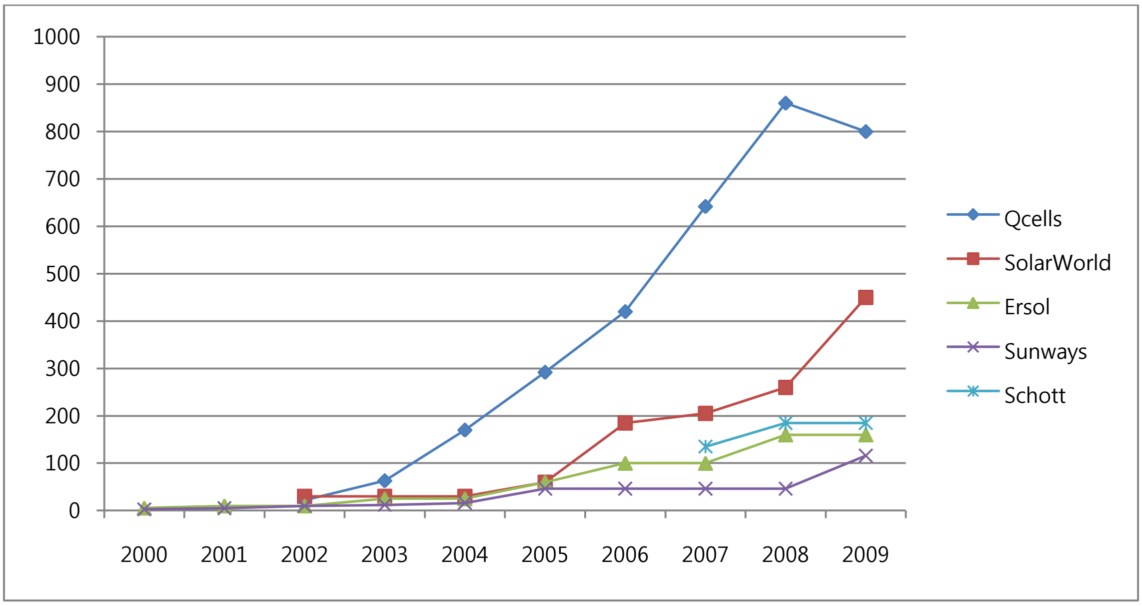
Source: firms’ annual reports and web sites

3.3.2.2 Rapid Expansion of Production Capacity

According to KPMG (1999), there are three ways to achieve cost reduction in PV electricity: technological development, government subsidy and scale-up of production. Considering the big price gap between PV electricity and conventional electricity, government subsidy can result in a large budget deficit. Also, technological development such as thin-film technology is only likely to be accomplished in the long-term. Therefore, expansion of production capacity is the most feasible way to achieve cost reduction of PV systems in the short-term (KPMG, 1999). In fact, the report argues that a 500 MWp of annual production capacity is capable of providing us with PV modules at 0.91 Euro/Wp (KPMG, 1999). If this is accomplished, it enables PV electricity to compete with conventional electricity without any government subsidy.

The new generation of PV firms in Germany seem to have followed this strategy. They have made an effort to expand their production capacities as fast as they can in order to achieve economies of scale. In particular, Q-Cells and SolarWorld took a lead, the former attaining a capacity of over 800 MWp and the latter reaching nearly 500 MWp by 2009. Figure V-18 illustrates their rapid expansion.

Figure V-18 Production capacity of the new generation of PV firms (unit: MWp)



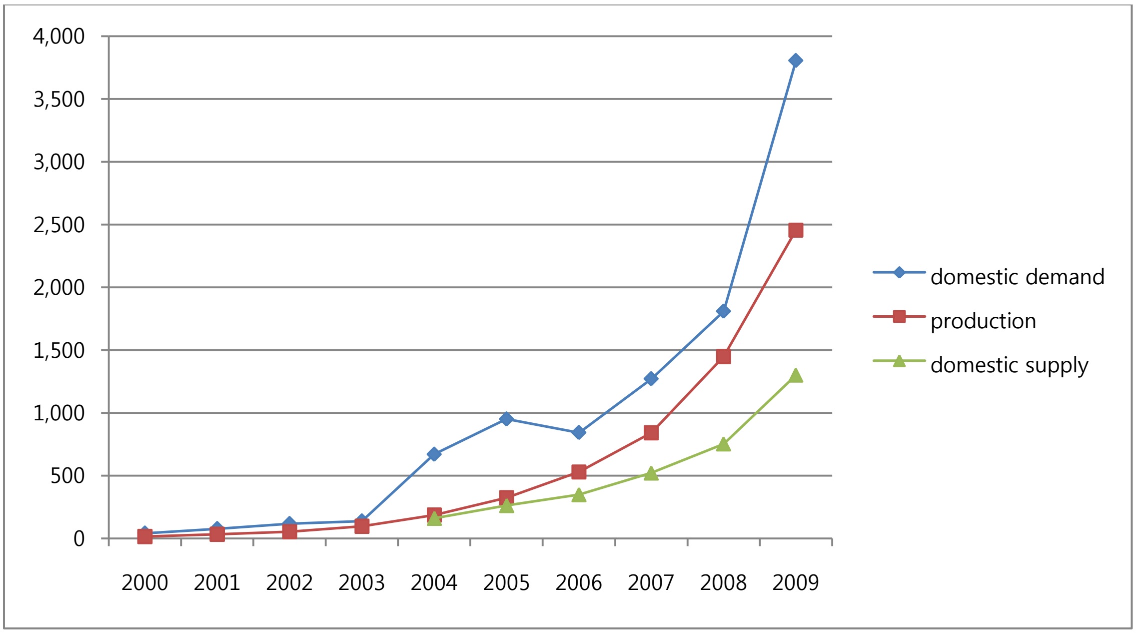
Source: Each firm's annual report and web site

There were two fundamental circumstances that enabled them to achieve rapid expansion: one was a well-developed financial market; the other was the tremendous growth of the domestic PV market. With regard to financing, firstly, the new generation of PV firms utilised the German stock markets to mobilize funds to invest in new production capacity. Initial Public Offering (IPO) was the main method for them to tap into capital. SolarWorld launched on the Düsseldorf Stock Exchange with an IPO in November 1999. In February 2001, Sunways was listed on the Frankfurt Stock Exchange, with the net proceeds of the issue raised for the company amounting to approximately 16 million Euros. The IPOs of Ersol and Q-Cells on the Frankfurt Stock Exchange were successful, with the net proceeds of approximately 153 and 240 million Euros raised respectively in September and October 2005. After the IPOs, these companies placed new shares on the stock market to increase capital several times. SolarWorld, for instance, received liquid funds worth 233.7 million Euros by the placement of new shares in 2006. Secondly, they issued corporate bonds and convertible bonds in order to be able to implement their investment plans. For example, Sunways issued convertible bonds in a nominal amount of 10 million Euros in 2004, and SolarWorld sold its corporate bond with seven per cent yield for seven years in

2004. Thirdly, they utilised bank loans only as part of their long-term investment plans. For instance, SolarWorld financed less than 45 per cent of its expansion costs through banks in 2004. Furthermore, they were provided with substantial grants and subsidies by governments for their investments, as I describe later (V.3.3.2.5).

Concerning the growth of the domestic PV market, as described earlier (V.3.3.1.3), due to the feed-in tariff scheme, the German PV market has grown faster than any other country in the world. Consequently, the German PV industry has been led mainly by the expansion of the domestic market, even though its export ratio has increased as shown in Table V-4. In terms of PV support policy such as the 100,000 roof programme and the increase of feed-in rates, most of the new generation of PV firms expected tremendous growth of demand for PV and invested heavily. In reality, expansion of the market was realised and they supplied the market with PV products. Figure V-19 shows us the PV demand and supply in Germany.

Figure V-19 PV demand and supply in Germany (unit: MWp)



Source: ‘Statistical data on the German PV industry’ (BSW, 2010)

Table V-4 Export ratio in the German PV industry

	2004	2005	2006	2007	2008	2009
%	14	19	34	38	48	47

Source: ‘Statistical data on the German PV industry’ (BSW, 2010)

3.3.2.3 Cost Reduction through Technological Development

As I note in the previous sub-section (V.3.3.2.2 p. 100), development of technology is one of the ways that enables the German PV industry to grow. In fact, cost reduction and improvement of conversion efficiency of crystalline silicon PV cells have been achieved mainly by the new generation of PV firms. Cost reduction was accomplished mainly by process innovation, namely, improvement of the existing production process and introduction of a new method of production process. For example, decreasing wafer thickness directly results in cost reduction by saving poly silicon material which normally accounts for about 30 per cent of the value of PV cells. In fact, Q-Cells and SolarWorld have attained a decrease of wafer thickness from 330 μm[57] to 180 μm, as shown in Table V-5. This means that the consumption of poly silicon is reduced by about 45 per cent.

Table V-5 Decrease of wafer thickness (unit: μm)

	2003	2004	2005	2006	2007	2008
Q-Cells	330	275	230	200	180	
SolarWorld			240	210		180

Source: Each firm's annual report

Another process innovation in the production of crystalline-silicon PV cells is string ribbon technology. Instead of sawing wafers from silicon ingots with wire saws as in the conventional method, two strings are used to grow silicon ribbon directly from molten silicon. Like a film of soapy liquid forms inside a bubble blower, a silicon ribbon forms between two strings. The silicon crystallises between the strings and is then cut into wafers with a laser. This new process can reduce silicon consumption by 30 to 35 per cent because of no sawing waste. In fact, EverQ GmbH (present Sovello), a joint venture between Q-Cells and the US Evergreen Solar, commercialised this technology in 2005.

Improvement of cell efficiency has been another technological goal in reducing the cost of PV electricity. In fact, the new generation of PV firms have achieved around 30 per cent increase of efficiency from 14 % to 18 %, as listed in Table V-6.

[57] Micron meter is a unit of length equal to one millionth (10^{-6}) of a meter.

Table V-6 PV cell efficiency of the new generation of PV firms (unit: %)

		2002	2003	2004	2005	2006	2007	2008	2009
SolarWorld	Poly	14	15					18	
	Mono							20	
Q-Cells	Poly						17		
	Mono				20.5* (100cm²)				17.4
Sunways	Poly	14	15.7						16
	Mono		16.7						18.4

Source: Each firm's annual report

Poly: Poly crystalline silicon cells

Mono: Mono crystalline silicon cells

* a medium sized industrially applicable cell

Although their R&D personnel ratios are around 5 to 10 per cent (Sunways: 10.4, Q-Cells: 7.8, Schott Solar: 6, SolarWorld: 4.5), basically, their technological achievements have been achieved by cooperation with other actors such as research institutes, universities, equipment suppliers, technical companies, and competitors. In other words, these companies benefit from access to the comprehensive knowledge and long-standing experience of renowned research institutes, universities and also sometimes other solar companies, and are not self-sufficient in developing technology. Firstly, they have cooperated with world leading research institutes and universities such as the Fraunhofer Society and Konstanz University in the research of PV technology. Sometimes they participated in government research projects and sometimes they contracted licensing with research institutes and technical companies. This kind of industry-university or -research institute cooperation has been a strong tradition of the German political economy since the late nineteenth century, as I mention earlier (V.2.1 p. 69). It is the strong partnership with world leading research institutes and universities that is one of the institutional advantages which makes the German PV industry a world leader. Table V-7 summarises this kind of cooperation in the German PV sector.

Table V-7 Cooperation with universities/research institutes

	Research institutes and universities	Project or technology
Q-Cells	ISE Fraunhofer Institute for Solar Energy Systems IFSH Institute for Solar Energy Research CSP Fraunhofer Center for Silicon PV Energy Research Centre of the Netherlands (ECN)	Efficiency improvements Ultra-high-efficiency cells Thin film processes Polycrystalline production Contact placement

	Helmholtz Centre University of Konstanz	
SolarWorld	Technical University of Freiberg Fraunhofer Society Energy Research Centre of the Netherlands (ECN)	Silicon recycling Semiconductor materials RGS (Ribbon Growth on Substrate)
Sunways	Konstanz University of Applied Sciences PROKON project (federal government's support) RGSell poject Solar Valley Central Germany research with nine partners ISE Fraunhofer Institute for Solar Energy Systems	Solar inverter Reverse contact solar cell RGS (Ribbon Growth on Substrate) Ultra thin cells (150μm) Exclusive license on inverters
Schott Solar	ISE Fraunhofer Institute for Solar Energy Systems German Aerospace Center Energy Research Centre of the Netherlands (ECN) Government project with Merck KGaA	Flexible, organic cells (efficiency: 10%)

Source: Each firm's annual report

Secondly, they have cooperated with other PV companies to incorporate Joint Ventures (JVs) and participate in stock holding of other firms. This kind of cooperation is summarized in Table V-8. This inter-firm cooperation was dominated by development of thin film technology which was not at a mature stage compared with crystalline-silicon PV technology. Whereas the industry-university or -research institute cooperation focused on silicon solar cell technology as their core competence, the inter-firm cooperation focused on thin film technology.

Table V-8 Cooperation with other PV firms

	PV firms	Technology
Q-Cells	JV (EverQ) with a US Evergreen JV (Solibro) with a Swedish Solibro AB CSG Solar (holding under 50% stake) Solaria (holding under 50% stake) Brilliant 234 (subsidiary) Calyxo (subsidiary) VHF-Technologies (subsidiary) Sontor (subsidiary)	String ribbon technology CIGS module (thin film) Crystalline silicon on glass (thin film) Low-concentration PV technology Micromorph technology (thin film) CdTe module (thin film) Flexible thin film Silicon based tandem thin film
SolarWorld	Cooperation with a US GT Equipment Tech. OEM with a Japanese Sharp JV (Joint Solar Silicon) with Degussa AG	Solar silicon Solar silicon
Sunways	Cooperation with Unaxis AG	Micromorph technology (thin film)
Schott Solar	JV (Wacker Schott Solar) with Wacker Chemie Cooperation with ersol Thin Film GmbH	Wafer Micromorph technology (thin film)

Source: Each firm’s annual report

Furthermore, they have collaborated with the German equipment industry which has been strongly competitive in the world market through the construction of the most modern semiconductor and electronics manufacturing facilities. Because almost all the production processes of PV cells are automated, equipment suppliers play a significant role in improving the production processes of solar cells. In fact, the six German equipment companies were among the top ten companies in the world, as shown in Table V-9, and their sales have increased along with the rapid expansion of the world PV production capacity, as shown in Table V-10. Proximity to the world leading equipment supplier is likely to be one of the technological advantages of the German PV industry.

Table V-9 Top ten companies in the solar cell equipment industry

ranking	company	nation	Sales in 2008(m. USD)
1	Applied Materials	The US	455
2	**Roth & Rau AG**	**Germany**	275
3	**Centrotherm GmbH**	**Germany**	270
4	Oerlikon Balzers AG	Switzerland	250
5	Ulvac Inc.	Japan	240
6	**Manz Automation AG**	**Germany**	140
7	**Schmid GmbH**	**Germany**	125
8	**Von Ardenne GmbH**	**Germany**	120
9	**Rena Sondermaschinen GmbH**	**Germany**	85
10	Swiss Solar Systems	Switzerland	70

Source: VLSI research study, 2008

Table V-10 Sales of the German PV machinery manufacturers (unit: Euro billion)

	2005	2006	2007	2008	2009
Sales (billion Euro)	0.2	0.5	0.9	2.4	2.0
Export ratio (%)	31	37	40	68	79

Source: BSW, 2010

3.3.2.4 Vertical Integration within the Value Chain

Generally speaking, the silicon-crystalline PV value chain is composed of four parts: poly-silicon (raw material); ingots and wafers (intermediate goods); cells (intermediate goods); and modules (finished goods). Within the value chain, boundaries of the firm seem to have a tendency to expand forward or backward. However, the degree of vertical integration within the value chain is mainly determined by consideration of three factors: economies of scale; economies of scope; and economies of diversification (Dunford and Greco, 2006).

Dunford and Greco (2006) argue that economies of scope especially influence the decision of firm boundary within the value chain as follows:

> Economies of scope are connected with the range of products a firm makes. This range depends in part on the degree of vertical integration upstream into activities supplying inputs and downstream into activities involving further transformations of the commodities it produces. In these cases the scope of a firm depends on a series of 'make or buy decisions' and on choices between markets and hierarchies as coordination arrangements. These decisions depend on relative internal and external production costs and the costs of organization of economic activities. Organization costs comprise (1) the costs of internal coordination, which increase as a firm integrates upstream and downstream, and (2) transaction, or external coordination, costs, which increase as vertical integration declines and the volume of market transactions or transactions across a firm's boundaries increases (Dunford and Greco, 2006, p. 50).

In other words, the strategies of integration are decided on the basis of the sum of production costs, internal coordination costs, and external transaction costs. Firms tend to minimise the sum of these costs through the decision of firm boundary within the value chain.

Furthermore, from this perspective, value chains can be categorized into three types of production networks: market relations; vertical near-integration; and vertical integration (Dunford and Greco, 2006). When coordination costs are lower, information are more available, and asset specificity are lower, market relations are more appropriate, while the opposite is vertical integration. Vertical near-integration is favoured somewhere between them (Dunford and Greco, 2006).

Two contrasting cases are Q-Cells and SolarWorld. Q-Cells can be a representative model for ‘vertical near-integration’, while SolarWorld can be a representative model for ‘vertical integration’. Firstly, in terms of production capacity, Q-Cells has focused on the specification of cell production, while SolarWorld has extended its production value chain from wafers to poly-silicon demonstrating backward integration and from wafers to cells and modules demonstrating forward integration. Thus, Q-Cells has concentrated on the faster expansion of solar cell production capacity, while SolarWorld has completed the vertical integration from silicon to modules, as shown in Table V-11.

Table V-11 Annual production capacity within the value chain (unit: MWp)

	Value chain	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Q-Cells	Cells			22	63	170	292	420	645	860	800
SolarWorld	Poly-si*(ton)						2	810	1,200	2,250	
	Wafers	32	55		120		180	245	385	600	900
	Cells			30			60	185	205	260	450
	Modules		10		50	54	90	140	185	310	500

Source: Each firm’s annual report

* Including recycling capacity

Secondly, however, Q-Cells has sought to secure stable vertical customer-supplier relationships through vertical near-integration rather than via market relations. In fact, it tried to establish strong partnerships with suppliers and customers who are shown in Table V-12. For example, it bought 17.2 per cent of the shares of the Norwegian company REC (Renewable Energy Corporation), which was the world’s largest manufacturer of poly silicon and silicon wafer, in order to consolidate a strategic partnership.

Table V-12 Q-Cells’ strategic partners in the value chain

Value chain	2004	2005	2006	2007	2008
Poly-si		REC	REC	Elkem Solar (Norwegian)	Timminco/BSI
Wafers	ScanWafer (REC group)			LDK Solar (Chinese)	
Modules		Solon AG (German)			

Source: Q-Cells’ annual reports

Another issue related to value chains is relocation of production facilities to lower-cost, overseas areas. Q-Cells moved its production facility from Germany to Malaysia in 2008, and Schott Solar have operated a factory at Valašskè Meziříčí in the Czech Republic. In addition, due to the trade barriers and local incentives, SolarWorld constructed production capacity in Hillsboro in Oregon, USA, and Schott Solar built a factory in Albuquerque in New Mexico, USA.

3.3.2.5 Other Government Support

The feed-in tariff is not the only form of government support. Other government support includes the establishment of ‘Solar Valley Central Germany (*Solarvalley Mitteldeustchland*)’. This cluster policy has played a major role in the success of the German PV industry. The ‘*Solarvalley Mitteldeutschland*’ consists of three *Länders* as follows under the sponsorship of the Federal Ministry for Education and Research (*Bundesministerium für Bildung and Forschung*): the Free State of Thuringia (*Thüringen*), the Free State of Saxony (*Sachsen*), and the Saxony-Anhalt (*Sachsen-Anhalt*) (Solarvalley Mitteldeutschland, 2010). The cluster members are 29 global PV companies, 9 renowned research organizations, and 4 universities (Solarvalley Mitteldeutschland, 2010). Its support policies are mainly investment grants, R&D subsidies and reduction of operating costs. Investment grants are allowed to cover up to 30 to 50 per cent of eligible investment costs, and R&D projects are provided with subsidies to cover up to 50 to 80 per cent of their expenses by the *Länder* (LEG, 2009). Furthermore, 80 to 100 per cent of costs for training and qualification of employees are paid for by the *Länder* (LEG, 2009). These supports are connected to the European Structural and Cohesion Funds, as I mentioned in sub-section 2.3.2.

In fact, a total budget of 150 million Euros has been allocated to 98 joint projects over five years, half of which is being financed by the public sector (Solarvalley Mitteldeutschland, 2010). Q-Cells, Sunways, SolarWorld, and Schott Solar have participated in these projects. With regard to investment grants, these subsidies seem to be more helpful to start a new PV company in former eastern German area in the 1990s. According to interviews, public subsidies from the European Union and the state government accounted for 35 per cent of the initial financing of Deutsche Solar AG (a current SolarWorld AG) company in 1994 (Woditsch, 2011). And Saxony-Anhalt state's subsidy influenced strongly on the decision of Q-Cells to locate in Thalheim, when it was looking for a site to construct a large solar cell factory in 2000 (Seifert, 2011). Furthermore, according to firm's annual reports, SolarWorld was provided with 73 million Euros for the expansion of solar factories in Freiberg of Saxony in 2003, and Q-Cells received a grant of approximately 21 million Euros for the construction of factories in Thalheim of Saxony-Anhalt in 2004.

Mainly due to these supports, approx. 75 per cent of all solar cell production in Germany and approx. 65 per cent of German PV manufacturers are located in the '*Solarvalley Mitteldeutschland*' (Solarvalley Mitteldeutschland, 2010). The main PV companies in the cluster are listed in Table V-13.

Table V-13 Main PV companies in the Solarvalley Mitteldeutschland

State	Wafers	Cells	Modules
Thuringia	Bosch Solar in Arnstadt Schott Solar in Jena PV Crystalox in Erfurt	Bosch Solar in Erfurt Sunways in Arnstadt	Bosch Solar in Erfurt Schott Solar in Jena
Saxony	SolarWorld in Freiberg	SolarWorld in Freiberg	SolarWatt in Dresden SolarWorld in Freiberg
Saxony-Anhalt	PV Crystalox in Bitterfeld	Q-Cells in Thalheim Sovello in Thalheim	

Source: Solarvalley Mitteldeutschland's web site

4. IMPACT OF INSTITUTIONAL ADVANTAGE ON THE NECESSARY FUNCTIONS

In this section, I shall examine the inter-relationship between the institutional advantages of the German political economy and the evolution of the German PV industry. In other words, I shall attempt to answer the question: what was the impact of institutional advantage on the four necessary functions (market formation, capital mobilisation, process innovation, and cost reduction) for the development of the PV industry?

4.1 Market Formation

After the Chernobyl accident in 1986, there were several demand-pull policies implemented to stimulate the PV market such as the 1,000 roof programme and the Aachen model. These policies were remarkable market creations compared to the previous space satellite market in the 1970s and the RDD programmes in the 1980s. Still, in terms of market size, these measures were not enough for the PV industry to grow fast. In fact, a substantial PV market was not created until the emergence of the Red-Green coalition government.

After taking over the government, the Red-Green coalition implemented the 100,000 roof programme and revised the feed-in law (EEG). The feed-in rate for PV electricity increased from 17 to 99 pfennig (approx. 50 Euro cents) per kWh in 2000. This was the most significant institutional change affecting the creation of PV markets in Germany. Due to this change, the German PV market has grown at an unprecedented rate and has become the largest in the world since 2005.

In terms of market creation, it is clear that Germany has an overwhelming institutional advantage compared to other countries. The German PV industry benefits from having the largest domestic PV market in aspects of logistics, marketing, producer-customer relationship, etc. Furthermore, the German PV industry seems to be relatively free from trade disputes and dependency on the global market compared to other countries. Thus, it is difficult to deny that the German PV market has contributed to the development of the German PV industry.

However, the growth of the German PV industry is attributable not only to the German PV market but also to other factors. The existence of a certain level of domestic market is not a sufficient condition for the development of a PV industry. Thus, it is necessary to examine other factors which contributed to the success of the German PV industry in the next sub-section.

4.2 Capital Mobilisation

Capital mobilisation is the essential function for the development of the PV industry, because the silicon solar cell industry is capital-intensive. Overall, the well-developed German financial market has enabled the German PV industry to mobilise capital so that it can invest in the expansion of its production capacity. In addition, investment grants and subsidies by governments have played a substantial role in starting and growing the German PV industry since German unification in the 1990s.

Firstly, banking loans have been one of the main sources of capital for the German PV industry, as they were for other German industries. Since the 19th century, it has been a tradition for the German bank to invest in promising industries such as the iron and steel industries, as I mention in V.2.1 (p. 67).

Secondly, the German stock market and corporate bond markets have played a critical role in raising funds for the German PV industry. In particular, when investors' expectation of the PV industry turned optimistic, German PV firms utilised this opportunity for fund raising. For example, Ersol and Q-Cells mobilised about 153 and 240 million Euros respectively through initial public offerings (IPOs) on the Frankfurt Stock Exchange in 2005.

Thirdly, government subsidies have been effective in boosting the growth of the German PV industry in terms of corporate financing. Since the unification of Germany in 1990, there have been many regional subsidy programmes which are co-financed by the European Union, the federal and state (*Länder*) governments (Klodt, 2003). The

German PV industry is one of the beneficiaries of these subsidy programmes. In particular, 'Solarvalley Mitteldeutschland' is one of the regional subsidy programmes, focusing on the PV industry in the three states: *Thüringen, Sachsen,* and *Sachsen-Anhalt*.

4.3 Process Innovation

Building a technological capability is one of the necessary functions for the development of the PV industry. In particular, process innovation was one of the main issues in the crystalline-silicon solar cell industry in the 2000s, as I discuss earlier (III.4.2.2 p. 52). Historically, Germany has had a strong tradition of collaboration between firms, research institutes, universities and other firms in terms of research and development since the nineteenth century, as mentioned in V.2.1 (p. 69). The German PV industry is not an exception.

Process innovation in the German c-Si cell industry has been achieved mainly in two fields: decreasing the thickness of wafers; and increasing the conversion efficiency of solar cells. In fact, the German PV industry has decreased the thickness of wafers from 330μm to 180μm and has increased the conversion efficiency of c-Si cells from 14 % to 18 %.

These achievements are largely attributable to the institutional advantage of the German economy in research and development. Firstly, the division of research and development is well-organised and well-developed between universities, research institutes, technical companies (most of them are small and medium-sized enterprises), joint ventures and other firms (Ettrich, 2011). Sometimes, intellectual property rights became a main issue in collaboration over R&D[58], but most of R&D was conducted through collaboration between them, as I describe in V.3.3.2.3 (p. 104). In addition, governments and public research institutes have encouraged technology diffusion and knowledge transfer through public funding for these R&D collaborations.

[58] According to an interview, one German PV company is reluctant to collaborate with other organisations in R&D, because it prefers monopolising knowledge and technology to sharing them with other firms (Ettrich, 2011).

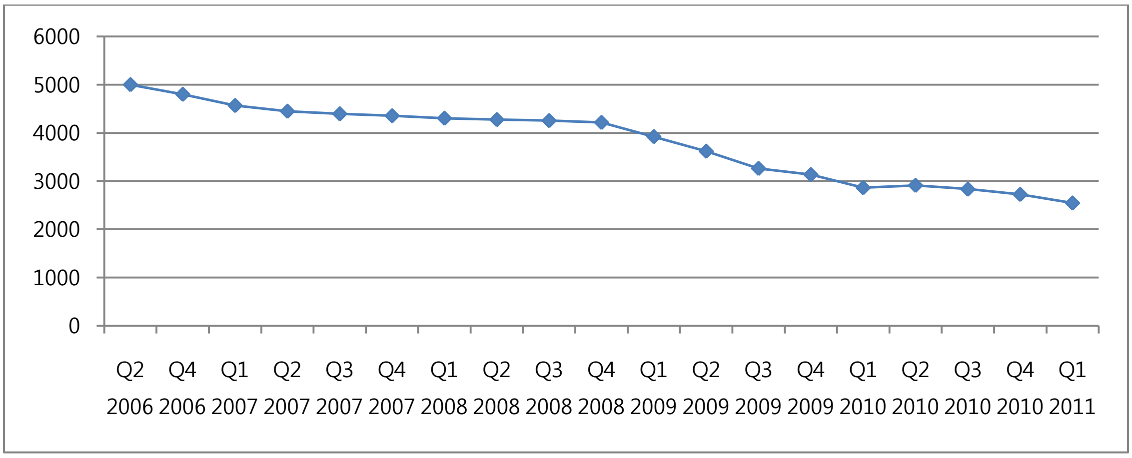
Secondly, the existence of competitive equipment suppliers has also contributed to process innovation in the German PV industry, because equipment suppliers are the main source of innovation in the PV industry. In fact, the world-leading German machinery industry has provided the German PV industry with state-of-the-art equipment, thus the production processes of German PV cell manufacturers improved.

In short, the German PV industry has been better at process innovation mainly due to the institutional advantage of the superior division of R&D and the existence of a competitive German machinery industry.

4.4 Cost Reduction

Average end-customer prices of PV systems[59] have decreased from 5,000 to 2,546 Euro/kWp since 2006 (BSW, 2011), as shown in Figure V-20. For five years, the price of PV systems has nearly halved. This is a consequence of dramatic cost reduction in the PV industry. Furthermore, according to the 'PV-Roadmap 2020' of the German Solar Industry Association (BSW), the price of PV system is expected to drop to 1,500 Euro/kWp by 2017 (Roland Berger SC and Prognos AG, 2010). If this price of PV systems is realised, installation of PV systems on the roof of house will be affordable by house owners without any support from the government (Chrometzka, 2011).

Figure V-20 Decrease of PV system prices in Germany (unit: Euro/kWp)



[59] To be precise, these prices are the system price for installed roof-mounted systems of up to 100 kWp (BSW, 2011). The PV system is mainly composed of PV modules and inverters. Thus, the price of a PV system is higher than that of a PV module.

Source: BSW, 2011

On the one hand, this cost reduction has been attributed to two main drivers: one is improvement of technology; the other is the achievement of economies of scale in production capacity. In the area of technological improvement, the German PV industry has an institutional advantage for process innovation, as I discuss in V.3.3.2.3. Moreover, the German PV industry has been capable of rapid expansion of production capacity, because it could afford to mobilise capital with support of the financial market and governments, as I discuss in V.4.2 (p. 112).

On the other hand, cost reduction has been pushed by the reduction of feed-in rates and global competition. In fact, the feed-in rate for PV electricity decreased from 50.6 Eurocents/kWh in 2000 to around 25 Eurocents/kWh in 2011[60] (Lauber and Mez, 2004; BSW, 2011). Furthermore, global competition has become more serious than ever before, especially due to the entries of Chinese PV companies. In particular, compared to the Chinese PV industry, the German PV industry has an institutional disadvantage in terms of other costs, such as labour costs and investment costs, etc. According to interviews, an initial wage of engineer who has a Master or PhD degree in PV firms is around 30,000 or 40,000 Euros/year respectively (Seifert, 2011). I shall discuss this issue in detail in chapter VIII (comparison of the three cases). To cope with these cost disadvantages, German PV firms attempted to relocate their production facilities to lower cost areas. Despite these efforts, the German PV industry has difficulty in competing with global competitors, mainly Chinese PV firms. This is a real challenge for the German PV industry to have to resolve in the near future.

[60] To be precise, the feed-in rates for PV systems in 2011 are as follows: building-integrated systems (28.74:<30kWp, 27.33:>30kWp, 25.86:>100kWp, 21.56:>1,000kWp); ground-mounted systems (21.11: commercial zones, etc., 22.07: conversion and sealed areas) (BSW, 2011)

5. CHAPTER SUMMARY

The aim of this chapter was to outline and explain the development of the German PV industry. The rapid development of this industry in Germany is, I have argued, a result of a set of political decisions to create a domestic market for solar energy and a number of other features of the German political economy.

In this chapter I dealt first with the emergence of Germany's particular institutional configuration: the social market economy and the coordinated market economy (CME). This configuration underpins Germany's strength in a range of manufacturing industries.

Secondly, I have explained the evolution of the German PV industry in the context of the German political economy. Strong political support for renewable energy sources resulted in the strongest demand-pull policy in the world. Furthermore, a strong tradition of collaboration between universities, research institutes and firms enabled the German PV industry to lead technological innovation.

Lastly, I have attempted to examine the inter-relationships between institutional advantage of the German political economy and development of the PV sector. Germany has an institutional advantage in creating PV markets, the feed-in tariff scheme being the best example. Moreover, the German PV industry has been one of the technical leaders, benefiting from the German national systems of innovation. In addition, well-organised financial markets and government subsidies have enabled German PV firms to mobilise capital so that they could expand their production capacities rapidly. However, despite the German PV industry's success in reducing costs, Germany has an institutional disadvantage in terms of cost reduction, in particular, that of higher labour costs.

CHAPTER VI PV INDUSTRY IN CHINA

1. INTRODUCTION

This chapter aims to investigate the emergence and growth of the PV industry in China. In particular, I shall shed light on the catching-up process of the Chinese PV industry and explain how China's institutional advantage facilitated the PV industry's development in terms of four drivers: market formation, capital mobilisation, process innovation, and cost reduction. China's institutional advantage has been changed along with the transition of China's political economy from a planned system to a market system. In order to explain the development of the PV industry and of these drivers of the industry's development attention must be paid to the political economy of contemporary China. Thus, it is necessary to start with an examination of the political economy of China and its historical foundations.

As in the German chapter, the structure of this chapter is composed of three sections: China's political economy; the evolution of the PV industry; and the impact of four drivers on the evolution of the PV industry. Firstly, in section 2, I shall examine in brief the history of China's political economy. After World War II, a planned economic system was established under the Chinese Communist Party. Since the economic reform and open door policy, a socialist market system has been introduced and China's economy has grown fast alongside the rise in foreign direct investment and international trade. Finally, by joining the WTO in 2001, China has integrated further into the global economy than ever before.

Secondly, in section 3, I shall analyse the catching-up process of the PV industry in China. Under the planned economy system, there were a few solar cell factories. These factories upgraded in the 1980s and 1990s, but they still fell far behind foreign PV companies. In the late 1990s, a new generation of PV firms emerged in China. In an initial stage, these firms were strongly supported by local governments. As the global PV market expanded in the 2000s, they also grew fast and caught up with foreign leading companies not only in terms of production capacity but also in terms of technological capability.

Lastly, in section 4, I shall analyse how the four drivers functioned in the process of catching-up. In terms of mobilising capital, mainly due to local state corporatism, the Chinese PV industry succeeded in raising funds despite the high risk of investing in the early 2000s. After market conditions became more optimistic, foreign stock markets had a key role in mobilising capital for the Chinese PV industry. With regard to market creation, despite an insufficient domestic market, the Chinese PV industry grew fast mainly due to successful penetration in the European PV market. Moreover, the new generation of PV firms improved through importation of cutting-edge equipment and learning by manufacturing. In addition, in order to achieve cost reduction they utilised cost advantages in China such as low labour costs, low R&D costs and low expansion costs.

2. POLITICAL ECONOMY OF CHINA

2.1 Planned Economy : 1950s – 1978

After the Second World War in 1949, the Chinese Communist Party (CCP) led by Mao Zedong established the People's Republic of China (PRC). At this time, Chinese leaders chose 'a heavy-industry-oriented development strategy' in order to recover, and modernise China's war-torn agrarian economy by turning it into an industrialised one[61] (Lin and Cai, 1996). Moreover, partly due to the influence of the former USSR, Soviet-style industrial organisations were introduced and an extensive range of technologies was imported from the former USSR[62] (Liu and White, 2001). As a consequence, this strategy, in concert with socialist ideology, resulted in forming a central planned economic system in China (Lin and Cai, 1996).

In 1952 the CCP set up the State Planning Commission (SPC) which had ultimate control over economic plans and resource allocation (Pyle, 1997; Liu and White, 2001). '[The SPC] issued annual and 5-year plans that dictated both the operational and "strategic" objectives and activities of primary actors. This included new R&D and production project selection, capital and labour allocation, production levels, price-setting, distribution and others' (Liu and White, 2001, p. 1097).

Under the SPC's planning, the central government and governmental industrial bureaus managed functionally specialised organisations by deciding and regulating their activities (Liu and White, 2001; Marigo, 2009).

Government research institutes and state-owned manufacturers, namely factories[63], were

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[61] Lin and Cai (1996) argue that Chinese leaders selected 'a heavy-industry-oriented development strategy' because of the following reasons. 'At that time, a developed heavy-industry sector was the symbol of the nation's power and economic achievement' (Lin and Cai, 1996, p. 202). Furthermore, for national security, China needed to industrialise itself as soon as possible to have capital goods and military materials (Lin and Cai, 1996).

[62] 'During the first 5-year plan in the early 1950s, China imported 156 large turnkey facilities, mostly in heavy industry, power generation, mining, refining, chemicals and machine tools' (Liu and White, 2001, p. 1097).

[63] In the period of the planning system, manufacturers' main activities are production activities under the quantity target. Compared to normal firms under the market mechanism which is operated by demand and supply, these manufacturers have little management autonomy. From

under the control of the government (Marigo, 2009). The role of government research institutes was to carry out research in accordance with the government plan (Marigo, 2009). Factories produced their products in accordance, not with market demand, but with production targets set by the government (Marigo, 2009).

In short, the planned economy was fundamentally different from the market economy in that administrative activities replaced market mechanisms in allocating resources and setting prices of goods and services.

In view of innovation theories, the planned economic structure had two significant characteristics compared with the market economy during the period before economic reform: one was the lack of incentives for actors to innovate their economic activities; the other was the lack of incentives for actors to interact with others (Liu and White, 2001; Marigo, 2009).

Firstly, there was no incentive for researchers and factory managers to import or imitate a new technology or to innovate proactively. ‘There was neither market competition, profit, nor other operational efficiency-based criterion for performance’ (Liu and White, 2001, p. 1098). Thus, factory managers did not take any initiatives to innovate production processes or products (Gu, 2001). Therefore, this lack of incentive resulted in an ineffectiveness of the innovation system in introducing and improving technology in the factories[64] (Liu and White, 2001).

Secondly, there was no incentive for economic actors to share their field knowledge or feedback information. Research institutes, factory managers, distributors and users had strong relationships with the government or planners, mostly top-down relationships, while they had weak horizontal linkages amongst themselves (Liu and White, 2001).

As a result, the experience of daily operations of factories, feedback of information from distributors and users, and the basic and applied knowledge of researchers

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this perspective, I will describe these manufacturers as ‘factories’ in order to prevent confusion with the term of ‘firms’.

[64] ‘For example, the Liberation Truck, whose design and production lines China imported from the Soviet Union in the early 1950s, was unchanged during the 40 years that China has mass-produced it’ (Liu and White, 2001, p. 1098).

remained isolated sources of information rather than something to be shared and discussed.

However, there is another evaluation of Mao's era in terms of whether it contributed to the economic growth of China. Arrighi (2007) argues that China's economic success is based on the social achievements of the Mao era. He uses an example in the agriculture sector as follows.

> The boom in agricultural production of 1978-84 did have something to do with the reforms, but only because they built on the legacy of the Mao era. Between 1952 and 1978, the communes had more than doubled China's irrigated farmland and disseminated improved technology, such as greater use of fertilizers and high-yielding semi-dwarf rice, which by 1977 occupied 80 percent of China's rice land (Arrighi, 2007, p. 370).

Furthermore, China succeeded in restoring its economy from the devastated situation and accomplished to build the productive base during the planned economic period (Pyle, 1997; Arrighi, 2007). Many human development indicators such as 'literacy rate, daily calorie intake, death rate, infant mortality rate, life expectancy, and so on' (Nolan, 2004a p. 118 cited in Arrighi, 2007, p. 370) supported these economic and social achievements during this period. Therefore, although the annual economic growth rates in the Mao era were lower than those in the economic reform era, it would have been impossible for China to succeed in developing its economy during the economic reform era without these economic and social achievements during the planned economy.

2.2 Economic Reform: 1978 – 1980s

After the death of Mao in 1976, Deng Xiaoping seized power of the CCP in 1978 (Pyle, 1997). Deng's philosophy on socialism and his attitude to social change[65] became the cornerstone of Chinese economic reform from 1978 (Nolan, 2004b; Dunford, 2010a).

[65] Deng thought that poverty was not the symbol of socialism (Nolan, 2004b; Dunford, 2010a). In addition, pragmatism and gradualism were the key features of Deng's thoughts. Examples are as follows: 'truth to be found in practice' (Deng, 1979 cited in Nolan, 2004b, p. 7); 'I don't care if it's a white cat or a black cat. It's a good cat so long as it catches mice' (Deng, 1961 cited in Dunford, 2010a); and the approach on the social change like 'groping for stones to cross the river' (Nolan, 2004a, p. 1).

Transition from a planned economy to a market one began in agricultural and rural areas and extended to industrial and urban areas during the period between 1978 and the late 1980s. There were two fundamental institutional changes: one was the Household Responsibility System (HRS); the other was an emergence of Township and Village Enterprises (TVEs). The HRS, which included various forms of contracting systems in the agricultural sector, had replaced the commune system rapidly since 1979, reaching 99 per cent of the Chinese agricultural system by 1983 (Pyle, 1997). As a result, agricultural output grew at unprecedented rates between 1978 and 1984 (Pyle, 1997). By 1985 the CCP leadership had ended mandatory planning in the agricultural sector and henceforth targets were used only for guidance and reference (Pyle, 1997).

TVEs, which were not co-operatives but collectively-owned companies, were typically small business firms in the rural non-farm sector. They can be described as 'national state-owned enterprises, with the 'state' being the local community (*xiang* [township] and *cun* [village])' (Nolan, 2004a) under the monitoring of the local government. Despite superficial similarities, there were distinctive characteristics of TVEs which were fundamentally different from SOEs: contract-based relationships between the enterprise and workers; more autonomy for the manager of the enterprise, especially with regard to use of any profits (Nolan, 2004a). Arrighi (2007) argues the significant institutional changes which influenced the emergence of TVEs in the rural area were as follows:

> The emergence of TVEs was prompted by two other reforms: fiscal decentralization, which granted autonomy to local governments in the promotion of economic growth and in the use of fiscal residuals for bonuses; and a switch to the evaluation of cadres on the basis of the economic performance of their localities, which provided local governments with strong incentives to support economic growth. TVEs thus became the primacy loci of the reorientation of the entrepreneurial energies of party cadres and government officials towards developmental objectives (Arrighi, 2007, p. 362).

TVEs also influenced the state sector, because labour and capital in China began to move towards the sector with higher returns (Nolan, 2004a). As a consequence, TVEs paved the way to prosperity for China's local governments, and the rapid growth of

TVEs created rural jobs in the non-agricultural sector, from 28 million jobs in 1978 to 123 million in 1993 (Nolan, 2004a; Arrighi, 2007; Dunford, 2010a).

By contrast, SOEs were still largely controlled by the state in the 1980s, although many attempts had been made to handover responsibility. One of the main reasons which made the reform of SOEs difficult was the relationship with their workers. SOEs provided their workers with jobs for life – the so called the 'iron rice bowl' (Pyle, 1997). A labour contract system was introduced into SOEs in 1986, however, only 21 per cent of their workers were covered by this scheme by the end of 1992 (Pyle, 1997). Moreover, SOEs were still under the dual pricing system, which applied to inputs of raw materials in order to widen the influence of the market (Pyle, 1997).

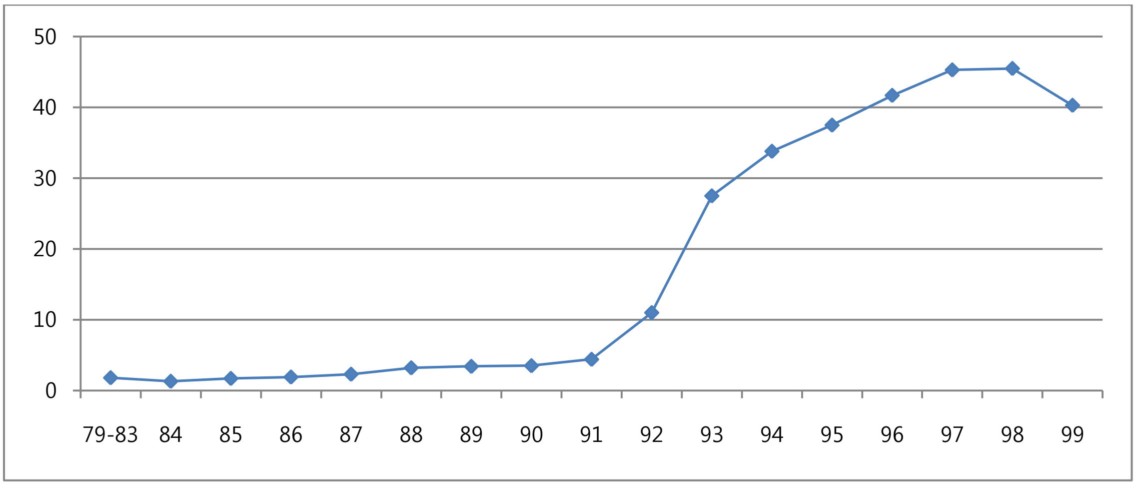
In regard to innovation theories, these economic reforms resulted in a fundamental change to China's systems of innovation. Liu and White (2001) argue that this system change led to two institutional changes. One was 'the change in the legitimate criterion for evaluating performance' (Liu and White, 2001, p. 1099), and the other was 'the decentralization of decision-making over both resource allocation within the economy and operational decisions within primary actors' (Liu and White, 2001, p. 1099). Therefore, these changes prevailed over almost all organizations including the agricultural sector, industries and research organisations during the economic reform period.

2.3 Fast Growth through FDI and Trade: 1990s

2.3.1 Surge of FDI

In the first few years after the adoption of an open door policy in 1978, the amount of foreign direct investment (FDI) in China was small, mainly due to uncertainty about the consistency of this policy. By the end of 1983, 'the cumulative amount of FDI actually undertaken in China was less than $US 2 billion or rather less than 1 per cent of China's GDP' (Pyle, 1997, p. 110). However, after Deng Xiaoping's visits to the four Special Economic Zones (SEZs) (Shenzhen, Zuhai and Shantou in Guangdong Province and Xiamen in Fujian Province), China gradually extended open regions from four SEZs, to fourteen coastal cities and further to three golden triangles (the Pearl River delta, the Yangtze River delta, and the south Fujian River delta) despite ongoing controversies within the CCP. As a consequence, the amount of FDI in China soared rapidly in the first half of the 1990s and China became the recipient of more FDI than any other developing country by the mid-1990s (Lardy, 1995). Figure VI-1 shows the rapid growth of FDI in China in the 1990s.

Figure VI-1 Foreign direct investment in China, 1979-1999 (unit: USD billion)



Source: ‘China Statistical Yearbook’ (NBSC, 2010)

Besides the opportunity of a potential market and cheap but well-educated labour, Lardy (1995) adds to the main causes of the dramatic increase of FDI in China as follows: the trend of FDI in developing countries in the 1990s; China’s political stability after the Tiananmen incident in 1989; attractive incentives for FDI (for example, special tax concessions and liberalised land leasing); and recycled capital of Chinese origin. However, Huang (2003) argues that the rise of FDI in the 1990s can be explained not only by a ‘supply perspective’ but also by a ‘demand perspective’. From the demand perspective, other determinants affecting the pattern of FDI were ‘the political pecking order of Chinese firms and the fragmentation of the Chinese economy’ (Huang, 2003, p. 3). Moreover, another driving force for FDI in China originated in local governments and institutions. For example, when SEZs were set up by the central government, local governments were more enthusiastic about expanding these regions than the central government (Pyle, 1997). According to Howell (1993 cited in Pyle, 1997), the Guangdong Party wanted the whole province to be designated as a SEZ and the Fujian Party was also lobbying for the introduction of a SEZ in its territory.

As I mentioned in the overseas Chinese model (II.2.2.2.3, p. 18), Chinese diaspora capital played a major role in opening up mainland China in the 1980s. Thanks to geographical, cultural, and linguistic advantages of overseas Chinese investors, they have enjoyed preferential treatment by the mainland Chinese in comparison to other foreign investors (Arrighi, 2007). Despite disadvantages compared to overseas Chinese capital, Japanese, American and European capital flooded into China in order to take advantage of China's economic expansion in the 1990s. In this way Japanese investment attempted to catch up with that of overseas Chinese investors in 1990 (Arrighi, 2007).

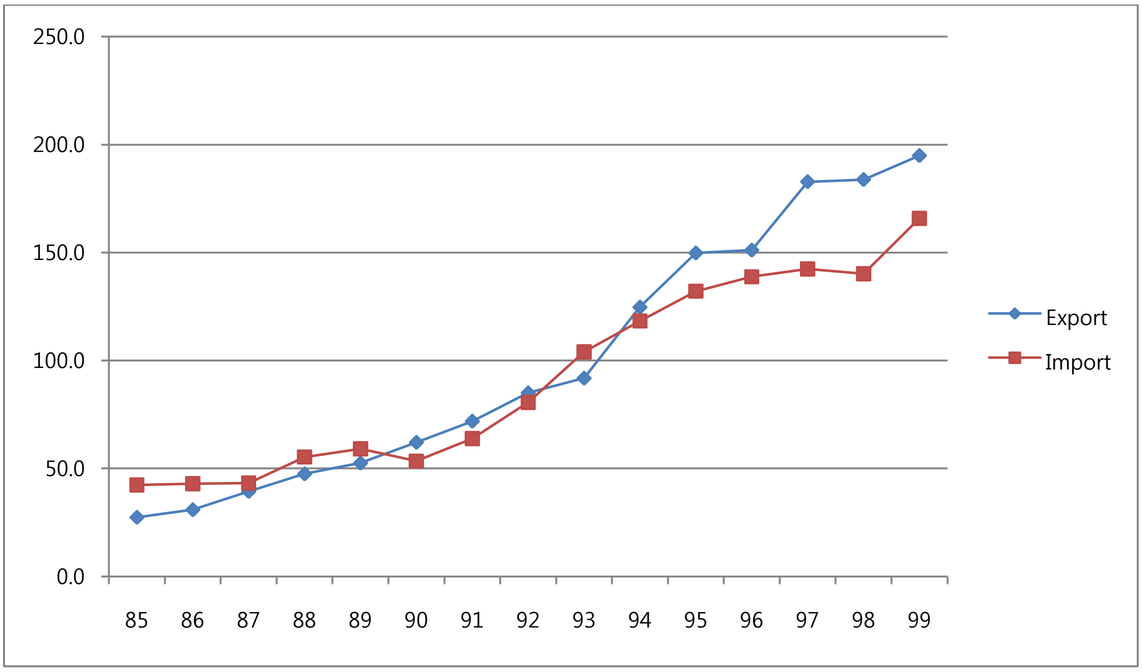
In view of the innovation approach, FDI can be regarded as one of the channels of technology transfer, as I mention in the latecomer firm model (II.2.3.2, p. 22) (Hobday, 1995). In fact, most of China's leaders hoped that FDI would facilitate technology transfer, thus some regulations and incentives which encouraged foreign companies to form joint ventures with local companies were introduced in the open door policy (Pyle, 1997). Although there seems to be no systematic evidence of spill-over effects of FDI in China at a national level, it is difficult to deny that FDI, to some extent, resulted in positive spill-over effects through reverse engineering, skilled labour turnovers, demonstration effects, and supplier-customer relationships, etc. (Young and Lan, 1997; Hu and Jefferson, 2002; Cheung and Lin, 2004). However, the performance of joint ventures between SOEs and foreign companies in particular was not sufficient to satisfy China's leaders (Young and Lan, 1997).

However, this does not mean that FDI was the only channel of technology transfer. Indeed, the Chinese government has made an effort to build China's innovation capability mainly through its science and technology policy. For instance, many R&D programmes have been carried out by public funds and overseas Chinese scientists and engineers have been encouraged to return to mainland China (OECD, 2007). Also, in the PV sector, many public R&D programmes were carried out and returned scientists played a key role in technology transfer, as I describe in details in the next section (V.3).

2.3.2 Trade on the Rise

As shown in Figure VI-2, the growth of international trade in China was phenomenal in the 1990s. Average annual growth rates of export and import in the 1990s were around 15 and 12 per cent respectively. While the balance of China's trade was in deficit in the 1980s, it turned to a surplus in the 1990s with the exception of 1993.

Figure VI-2 Foreign trade in China, 1985-99 (unit: USD billion)



Source: 'China Statistical Yearbook' (NBSC, 2010)

In terms of contents of trade, the main items of import were machinery, equipment and components, while the main items of export were labour-intensive manufacturing goods such as textiles, apparel, footwear and toys (Lardy, 1995; Pyle, 1997). As the flying geese model indicates (see II.3.2.1, p. 31), mature industry relocated in China in the 1990s. For example, simple electronic goods such as televisions, radios and telephone equipment were assembled with imported parts and components in Chinese factories (Lardy, 1995; Pyle, 1997).

With regard to firm-types and their export performance, foreign invested firms and TVEs performed better than SOEs (Lardy, 1995). In fact, the contribution of foreign invested firms to total exports in China increased rapidly from 1 per cent in 1985 to 48 per cent in 2000 (Lardy, 2002).

2.3.3 Fiscal/Tax Reforms

Fiscal reform has been one of the most important institutional changes during the process of industrialisation in China. Overall, the direction of fiscal reform in China was to allow 'greater fiscal autonomy' (Pyle, 1997, p. 141) and incentives for local development (Oi, 1999). The first fiscal reform was introduced in 1980 as a tax revenue shared between local and central governments by contracting[66] (Pyle, 1997). Basic principles of the fiscal reform were that '(i) revenue shares were fixed for four or five years (and not renegotiated each year), (ii) provinces determined the structure and level of their local spending (no longer were they told what they must spend in their local community) and (iii) provinces were held responsible for balancing their budgets and could not expect central government 'to get them out of gaol''(Pyle, 1997, p. 141).

According to Oi (1999), this fiscal reform significantly changed the incentive system for local governments as follows:

> First, the central state no longer guaranteed upper-level budget allocations to meet local expenditures. China converted a vertical (*tiao*) apportionment system that had allocated revenues from the upper to the lower levels into a system in which localities had to rely primarily on horizontal flows (*kuai*) – that is, on income that they generated themselves. The impact of the 1980s reforms is captured by the colloquial phrase "eating in separate kitchens," the antithesis of the situation during the Maoist period when everyone "ate from one kitchen." Second, behaving more like a business organization than a public bureaucracy, China began to motivate its agents by granting local governments clear rights to any economic surplus that they were able to generate. Contrary to what some observers have argued, this surplus was not simply more "organizational slack"; it was a residual. The 1980s fiscal reforms eliminated the organizational slack for local governments, but it granted them rights to a residual. Even though these rights were granted to governments, not individual, the re-allocation of property rights gave localities positive inducements to promote rapid economic growth, which became not only a necessary strategy for bureaucratic survival but a *viable strategy for getting ahead* (Oi, 1999, p. 28).

[66] Revenue sharing was, in practice, quite complex. Fiscal contracts existed between the central state and each province, between each province and its prefectures, between each prefecture and its counties, and between each county and its townships, although was not instituted the reform down to township level in all areas (Oi, 1992).

The second fiscal reform was introduced in 1994, resulting in a change from the fiscal contracting system to a tax system for profit. The major changes were '(i) the establishment of a unified enterprise tax, (ii) extension of VAT to become the principal form of indirect taxation, (iii) revisions to the personal income tax and (iv) revisions of the revenue-sharing arrangements' (Pyle, 1997, pp. 142-143). At the expense of a taxation authority, local governments accepted this reform expecting less interference by central government and more tax revenue with an efficient tax system (Pyle, 1997).

As a result, fiscal/tax reforms have provided local governments with strong incentives to encourage fast growth of industries in their localities, as I describe earlier as 'local state corporatism' (II.2.2.2.2, p. 17) (Oi, 1992; Oi, 1999). This kind of local government activism played an important part in the development of the PV industry in China, as I will describe in detail later (V.3.3.3).

2.4 Joining the WTO and Globalisation: 2000s

2.4.1 Before and after Joining the WTO

After fourteen years of arduous negotiations, on the 11th December, 2001, China became a member of the World Trade Organization (WTO). Considering the massive institutional adjustments[67] necessary to comply with WTO obligations and the heavy costs entailed, one wonders why the Chinese leaders agreed to enter the WTO. However, there seem to be internal and external background factors which led to the decision to enter the WTO. Firstly, it was imperative for Chinese leaders to reform SOEs and financial institutions further, because they considered the decline of SOEs and nonperforming loans of banks to be a serious problem (Lardy, 2002). In fact, the share of SOEs went down from 64.9 per cent of gross industrial output in 1985 to 15.6 per cent in 2002 (Baek, 2005), and the rate of nonperforming loans of China's four big banks[68] was over 40 per cent of their total loans (Park, 2009). Secondly, it was likely

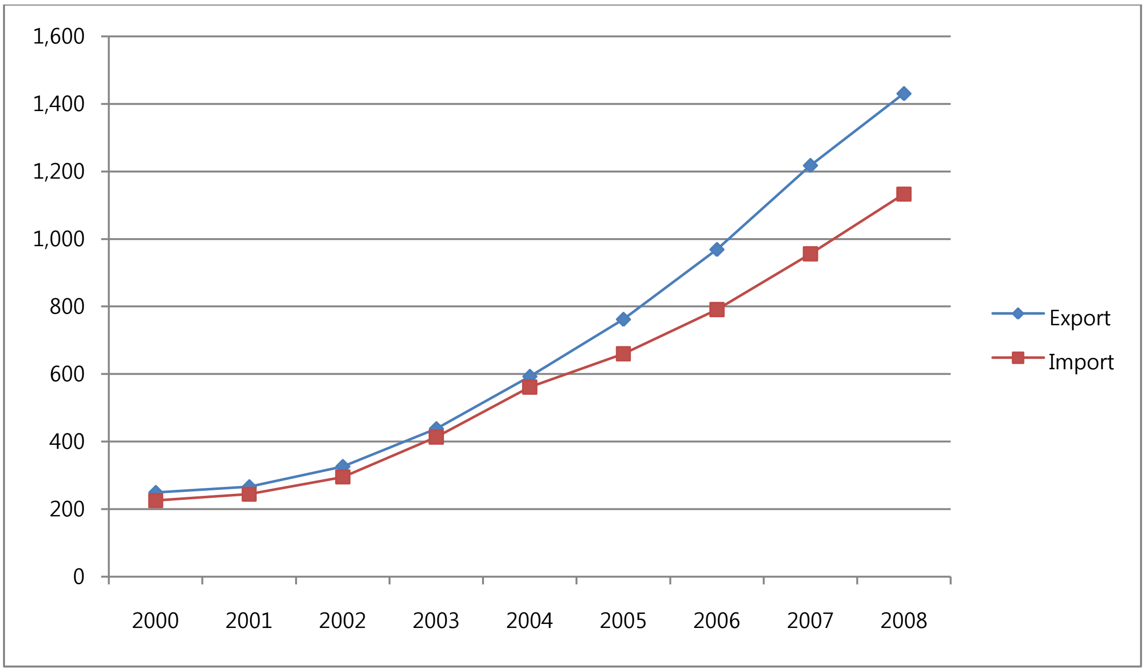
[67] For example, 'nine hundred Chinese laws will need to be changed and/or adapted for China to enter the WTO' (Nolan, 2001, p. 195).
[68] China's four big banks are Industrial and Commercial Bank of China, China Construction Ba

that the Asian financial crisis was a wake-up call for China, even though the crisis did not impact directly on the Chinese economy (Lardy, 2002). Similarly to Korea and some other countries in Southeast Asia, China's financial system was threatened by excessive loans to China's SOEs and insolvency problems (Lardy, 2002). Therefore, 'China's leadership envisages foreign banks and other foreign financial institutions as a source of competition that should improve the ability of domestic institutions to allocate resources to high productivity uses, contributing to greater economic efficiency and thus more sustainable growth' (Lardy, 2002, p. 16). More generally, China expected that its WTO accession resulted in removing import restrictions of trading partners and reducing tariffs on its exports. For instance, as a result of China's WTO accession China was granted a most-favoured-nation (MFN) status by the United States (Adhikari and Yang, 2002).

After joining the WTO, the performance of the Chinese economy was remarkable. As shown in Figure VI-3, exports and imports grew very fast. Eventually, China became the largest exporter in the world surpassing the second largest, Germany, in 2009 (WTO, 2010). More importantly, the composition of China's trade has changed since the late 1990s. In the early 1990s, light manufacturing goods such as footwear, clothing and toys accounted for more than 40 per cent of China's exports, whereas, in the 2000s, the share of more sophisticated goods in their exports increased gradually such as electronics, furniture and travel merchandise (Rumbaugh and Blancher, 2004; Li, Dunford and Yeung, 2011).

Figure VI-3 Foreign trade in China, 2000-2008 (unit: USD billion)

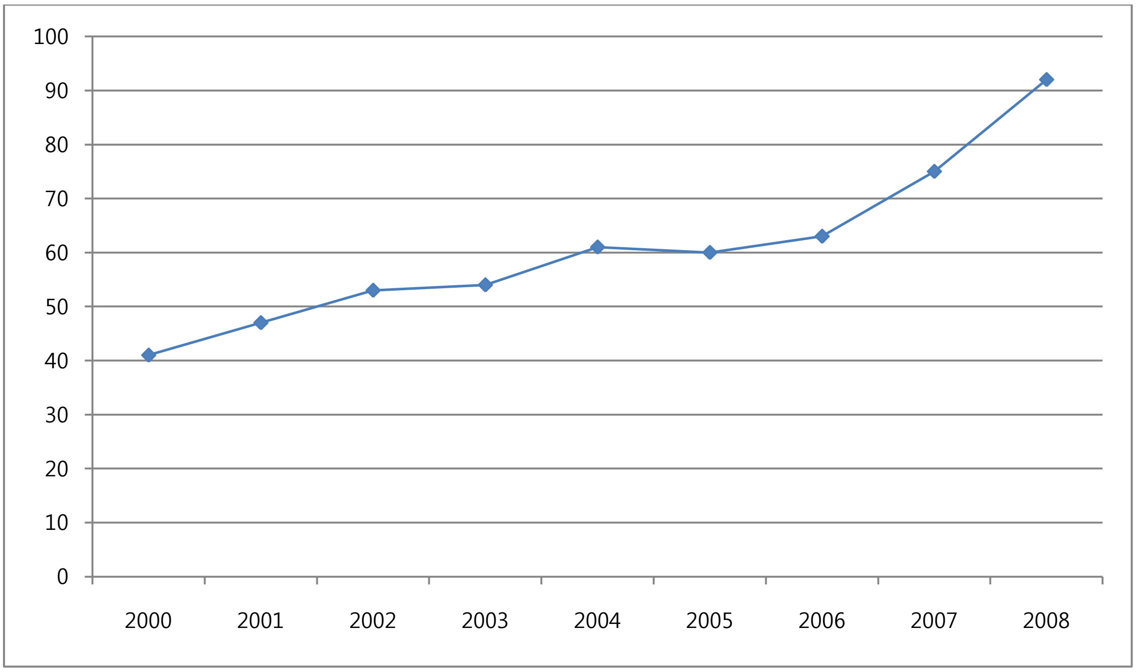
nk, Bank of China, and Agricultural Bank of China.



Source: 'China Statistical Yearbook 2005; 2009' (NBSC, 2010)

FDI also grew steadily, as shown in Figure VI-4, making China the second largest recipient of FDI after the USA, from the late 1990s.

Figure VI-4 Foreign direct investment in China, 2000-2008 (unit: USD billion)



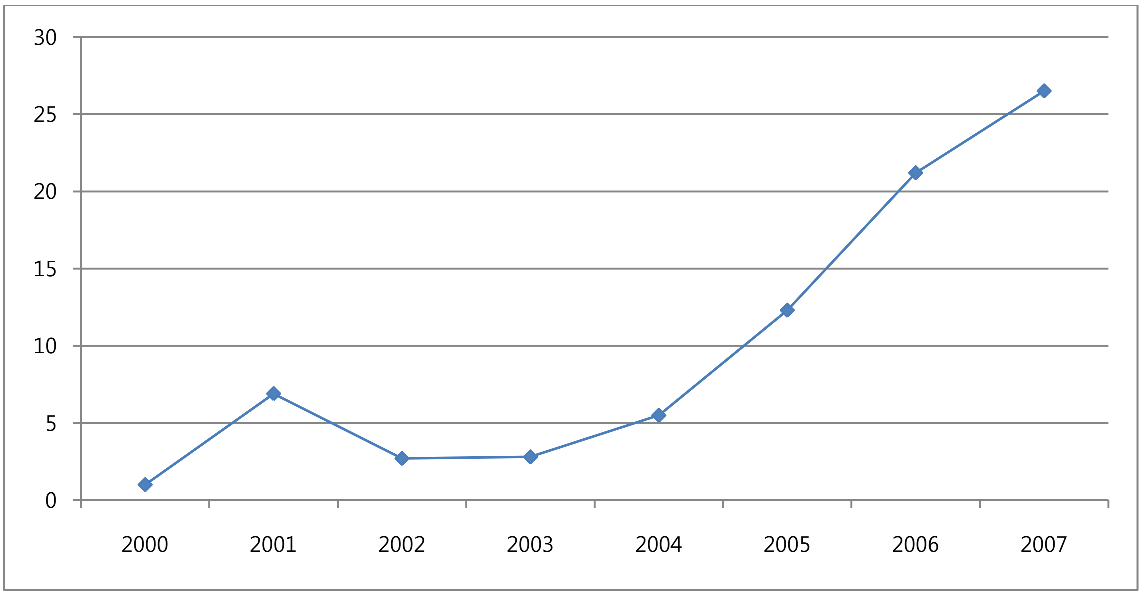
Source: 'China Statistical Yearbook 2009' (NBSC, 2010)

2.4.2 Outward Internationalisation of Chinese Firms

In the 2000s, listing on the foreign stock market became one of the main financial channels for Chinese firms[69]. At first, in the late 1990s Chinese firms such as China Mobile and PetroChina began to enter the Hong Kong Stock Exchange in order to tap the overseas capital pool. In fact, Chinese firms raised over USD 20 billion worth of funds from foreign stock markets in 2000 (Park, 2009). Chinese firms started to be listed on the New York Stock Exchange and the Nasdaq, and, in particular, small and high-growth information technology companies made initial public offerings (IPOs) in the US stock markets such as Chinese solar cell and module companies. The total worth of Chinese firms' IPOs on foreign stock markets were USD 20.5 billion in 2005 and USD 44.0 billion in 2006 (Park, 2009).

Another distinctive feature of Chinese firms in the 2000s compared with the 1990s is the surge in outward direct investment (ODI) of Chinese firms. According to the Ministry of Commerce of China (2008), the amount of ODI increased from USD 1 billion in 2000 to USD 26.5 billion in 2007. Figure VI-5 shows this increase.

Figure VI-5 Outward direct investment of Chinese Firms (unit: USD billion)



Source: 'The Statistical Bulletin of China's Outward Foreign Direct Investment 2007' (Ministry of Commerce, 2008)

69 Because there were institutional reforms such as reforms of company laws with regard to corporate governance in the 1990s, Chinese firms were able to be listed on the foreign stock markets.

The main reasons for the surge in ODI can be listed as follows: efforts for securing energy sources; attempts to access state-of-the-art technology through merger and acquisition (M&A); green field-type investments mainly in Africa and Southeast Asia; and the 'going global (*zǒuchūqū*) policy' under a huge amount of foreign reserves (Park, 2009; Cheung and Qian, 2009). Focusing on M&A, for example, Lenovo acquired a PC part of IBM in 2004, TCL acquired a TV/DVD part of Thomson in 2004, and Geely bought Volvo in 2010 (Park, 2009; People's Daily Online, 2010). In the PV sector, Suntech bought MSK, a high-tech Japanese solar module company, and Kuttler, a German PV equipment company, in 2006 and 2008 respectively.

3. EVOLUTION OF THE PV INDUSTRY IN CHINA

Unlike in the German case, Van de Ven and Garud's ILC theory does not seem to be relevant in analysing the evolution of China's PV industry. This is partly because the whole life cycle of the PV industry did not exist in China. In particular, the gestation period when basic knowledge was created, did not exist in the history of China's PV industry. Rather, Vernon's product life cycle theory is more relevant in examining the evolution of China's PV industry in that his theory explains relocation of the mature industry, as I discuss earlier (II.3.2.1 p. 32). Moreover, the evolution of China's PV industry was the process of catching-up with more advanced countries. Furthermore, before 1978, the Chinese economy was the planned system which was fundamentally different from the market economy.

Therefore, I shall divide the history of the Chinese PV industry into three periods: the planned economy period (1950s – 1978); the period of the traditional PV firms (1980s – mid-1990s); and the period of the new generation of PV firms (late 1990s – 2000s).

3.1 Under the Planned Economy: 1950s – 1978

3.1.1 Research and Fabrication of Solar Cells

As I describe in sub-section VI.2.1, in this period, research institutes and manufacturing organisations were owned by the government and their activities were under the control of the government. Within the planned economic system, basically the central and local governments ordered factories and research organisations to produce and conduct research through the top-down process.

According to the literature, the first research into solar cells in China began in 1958 (Cui *et al.*, 1990; CRED, 2000; Yang *et al.*, 2003; Marigo, 2009). However, hardly any research into solar cells seemed to take place due to various economic and political difficulties during the 1960s[70]. From the 1970s, the ministries of electronic industry,

[70] In the 1960s, the Chinese economy experienced negative growth twice mainly due to 'the

metallurgy, aeronautic industry, education, communication and railway started to fund research into solar cells for practical reasons (Cui *et al*., 1990).

The first application of solar cells in China was on the second space satellite in 1971[71] (Cui *et al*., 1990; Zhao, 2001). As the application of solar cells was extended from space satellites to terrestrial areas in Western countries, so the same extension of solar cell applications took place in China in the 1970s. 'PV lamps for railway stations of Qinghai, photovoltaic beacon light at Tientsin, and the telecommunication for the metrological observatory at mountain Huashan, Shaanxi' (Cui *et al*., 1990, p. 1011) are examples of solar cell usage in China.

With regard to the fabrication of solar cells, there were three factories producing solar cells during the 1970s. The first factory to produce solar cells in China was the 'Kaifeng Solar Cell Factory (henceforth Kaifeng factory)' which was founded in 1964 in Kaifeng City of Henan Province (CRED, 2000). Kaifeng factory started to produce mono-crystalline silicon solar cells from 1975 (CRED, 2000). The second factory was the 'Ningbo Solar Power Source Factory (henceforth Ningbo factory)' which was founded in 1976 in Ningbo City of Zhejiang Province (CRED, 2000). Ningbo factory was a state-owned factory subordinated to the Electronic Instrument Bureau of Ningbo (CRED, 2000). The third factory was the 'Yunnan Semiconductor Devices Factory (henceforth Yunnan factory)' which was founded in 1977 in Kunming City of Yunnan Province (CRED, 2000). Yunnan factory was also a state-owned factory under the Yunnan Chamber of Electronics and produced mono-crystalline silicon solar cells in 1979 (CRED, 2000).

These three factories, which were originally semiconductor production plants, converted their production lines into solar cell lines because the production processes for solar cells were similar to those for semiconductors at that time (Cui *et al*., 1990; Dai and Shi,

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Great Leap Forward' and 'the Cultural Revolution': one period was from 1960 to 1962; the other period was from 1967 to 1968 (Pyle, 1997). Furthermore, during the Cultural Revolution many scientists, technicians, and university professors were attacked and criticised (Pyle, 1997). Therefore, almost all research activities were shrunk during and after the Cultural Revolution.

[71] Since the 1950s the Chinese government had made an effort to develop technology capability in the fields of atomic energy, electronics, semiconductors, automation, computers and rockets under the 'National Science and Technology Long-Term Plan' (Liu and White, 2001). And then China achieved a success in launching a satellite in 1970.

1999; Marigo, 2009). However, the production cost of solar cells was around 400 RMB (approx. USD 206)[72]/Wp in 1976 (Cui *et al*., 1990) because semiconductor production processes were not fully modified for solar cell production. Although the applications of solar cells gradually extended, the amount of solar cells installed was still limited due to the high cost of solar cell manufacture. In fact, the total production of solar cells in China reached merely 0.5 kWp, 1kWp and 2kWp in 1976, 1977 and 1978 respectively (Cui *et al*., 1990). In short, the Chinese PV industry lagged far behind the advanced Western PV industry during this period.

3.2 Traditional PV Firms: 1980s – mid-1990s

3.2.1 Upgrading the Traditional PV Firms

Due to successful economic reform, economic activities in China became more vibrant than ever before and technological development and transfer systems changed. Horizontal links and interactions between various research institutions and between research institutions and enterprises increased, and research institutions became more independent of governments (Liu and Jiang, 2001; Liu and White, 2001). Although some enterprises asked research institutes to help them to solve specific problems, cases of strategic cooperation between them were still rare in China (Liu and Jiang, 2001).

In line with this trend, three traditional solar cell factories (Kaifeng, Ningbo and Yunnan factories), which were all small and medium-size SOEs, upgraded their production lines through importation of solar cell equipment in the 1980s. In 1984, Yunnan factory imported all equipment for its production line of mono-crystalline-silicon cells from the United States (Dai and Shi, 1999; CRED, 2000). In 1988, Ningbo and Kaifeng factories introduced advanced mono-crystalline-silicon solar cell technology through importation of the main key production equipment from ARCO (the US), Spire (the US) and British Petroleum (the UK), supported by the State Science and Technology Commission (Dai and Shi, 1999; CRED, 2000). Therefore, importation of

[72] In 1976, the official RMB/USD exchange rate was 1.94 (SAFE, 2010).

capital goods was one of the main ways for traditional PV firms to access and learn advanced PV technology.

In 1989, the ‘Huamei PV Equipment Company of Qinhuangdao (henceforth Qinhuangdao factory)’ entered into the solar cell sector. This state-owned company was jointly operated by the Hongguang Electronic Tube Factory and the Qinhuangdao Electronic Tube Factory in Qinhuangdao City of Hebei Province (Dai and Shi, 1999; CRED, 2000). Thus, the total number of traditional PV firms was now four. The location of them is shown in Figure VI-6.

Figure VI-6 Location of the traditional PV firms in China

Source: Author

① Qinhuangdao factory; ② Ningbo factory; ③ Kaifeng factory; and ④ Yunnan factory

Due to the upgrading of equipment and the entry of a new firm, the annual production of PV cells reached 400KWp in 1989 (Cui *et al.*, 1990). The production of solar cells in

China in the 1980s is shown in Figure VI-7 and Table VI-1. The production level of solar cells soared in 1988 because foreign advanced equipment was imported at this time.

Figure VI-7 Production of solar cells in China between 1978 and 1989 (unit: kWp)

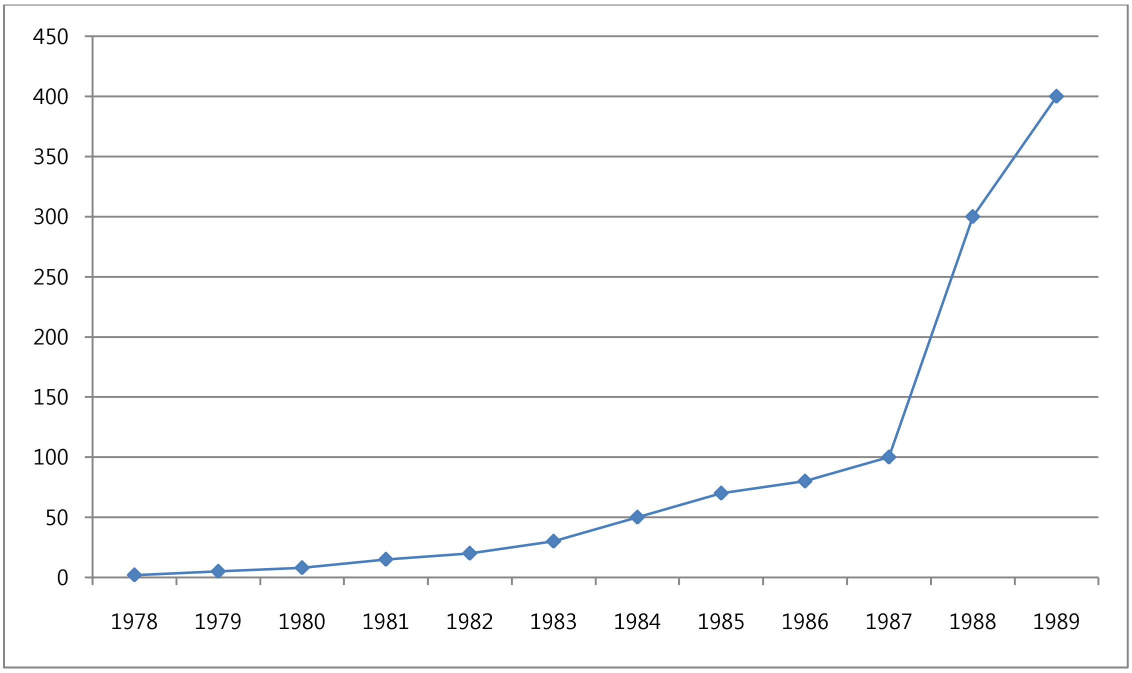

Table VI-1 Production of solar cells in China, 1978-1989 (unit: kWp)

Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
kWp	2	5	8	15	20	30	50	70	80	100	300	400

Source: 'Development of Photovoltaic in China: Status and Future' (Cui *et al*., 1990)

At this time, they employed over two hundred engineers and technicians and upgrading of production facilities and technological improvements were conducted by these local engineers and technicians[73]. However, the cost of solar cells in China was still higher than that of leading countries. It was around 40 RMB (approx. USD 11)[74]/Wp in the late 1980s, because they imported the equipment only once, and also the production capacity was not large enough to achieve economies of scale (Cui *et al*., 1990).

[73] There were over 200 engineers and technicians in the four factories in the 1980s. Approximately, 80 engineers and technicians worked for the Yunnan factory, 70 for the Qinhuangdao factory, 45 for the Ningbo factory, and 40 for the Kaifeng factory (CRED, 2000).
[74] In 1989, the official RMB/USD exchange rate was around 3.77 (SAFE, 2010).

3.2.2 Entry of Joint Ventures and Foreign Firms

Since 1978 Chinese leaders had adopted ‘the open door policy’ as one of the central themes of China’s modernisation strategy. However, the amount of FDI that actually flowed into China was small in the 1980s. From the early 1990s, FDI began to increase in China as shown in Figure VI-1 (p. 124). Moreover, China set up incentive systems to encourage joint ventures (JVs) in order to facilitate technology transfer from foreign partners to Chinese partners (Pyle, 1997).

Due to the incentive system for foreign investment in China, several JVs and foreign companies appeared in the solar cell sector as well as in other sectors in the 1990s. The ‘Harbin-Chronar Solar Power Company’ was the first JV solar cell firm in China. This company, which was set up by the Harbin Steam Turbine Factory, the Heilongjiang Movie Machine Factory and the Chronar Corporation of the US, produced amorphous-silicon solar modules and components from 1991 (Dai and Shi, 1999; CRED, 2000). Another JV solar cell firm was the ‘Shenzhen Yukang Solar Energy Ltd.’. This company, which was set up by the Shenzhen government and the Korean and International Finance Company, also produced amorphous-silicon solar modules and components from 1992 (Dai and Shi, 1999; CRED, 2000).

In the late 1990s, foreign solar cell companies rushed into China in order to sell their products, expecting a huge growth in the domestic PV market in China. This expectation was partly due to the electrification programmes of the northern and western provinces, as I describe in sub-section V.3.2.3.1. The foreign solar cell companies include: British Petroleum (the UK); Shell (the Netherlands); Siemens Solar (Germany); Sharp and Sanyo (Japan); SEC (the US) and Photomatt (France) (Dai and Shi, 1999).

Even though the electrification programmes were implemented, the growth of domestic PV demand was not sufficient for JVs and foreign firms to earn profits. Finally, the Shenzhen Yukang Solar Energy Ltd. shut down in 1997 mainly due to operational losses (Dai and Shi, 1999).

3.2.3 Central Government Support

3.2.3.1 Electrification of Northern and Western Provinces

About 80 million people had no access to grid electricity in the rural area of China at the end of 1995 (Stone *et al*., 1998; CRED, 2000). Almost all of them lived in northern and western provinces, including Xinjiang, Qinghai, Tibet, Gansu and Inner Mongolia Provinces, which were some of the poorest areas in China. Most of them also suffered from a lack of clean water. The Chinese government did make efforts to electrify these areas through its own electrification programmes and international cooperation (CRED, 2000).

Firstly, the Chinese government implemented a series of national projects in order to solve non-electrification problems in rural areas: the National Eight-Seven Poverty Alleviation Program[75], the China Brightness Programme[76] and the Project to Raise Income Levels of the Poor by Introducing Electricity[77] (CRED, 2000).

Secondly, China's international cooperation with Western countries and international organisations helped Chinese rural areas to electrify by harnessing renewable energy sources: the US Department of Energy (DOE) Project, the Netherlands' Shell Project, the Eldorado Program (a Sino-German project), the World Bank and Global Environment Facility (GEF) Project, the United Nations Development Programme

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[75] The aim of this program 'is to help 80 million people dress warmly and get enough to eat by concentrating man-hours, material, and financial resources during the last seven years of the century. … A large part of the population without electricity in these counties may use PV and wind power to resolve the problem. … Household PV systems were distributed to meet the basic electricity demands of peasants and herdsmen in five provinces of southwest China, Inner Mongolia, and Tibet. In 1996, 50-W and 100-W household PV systems were installed in 400 houses with no electricity. Two PV water-pumping systems with 800 W of solar cells were installed to irrigate orchards in poor mountain areas in Jianchang County of Liaoning Province' (CRED, 2000, pp. 62-63).

[76] In order to solve the problem of no access to electricity grid in rural areas, this programme built 'a certain number of PV systems to form some wind/PV, wind/diesel, and wind/diesel/PV hybrid systems'(CRED, 2000, p. 63).

[77] Due to this project, 'small independent PV stations and solar PV generation systems were distributed in the regions rich in solar energy such as Tibet, Xinjiang, Qinghai, Gansu, Ningxia, Shanxi, and Inner Mongolia. An independent PV station with an installed capacity of 100 kW was built in Naquanduo County in Tibet in October 1998. That makes six county-level PV stations, and installed capacity totaled 250 kW at the end of 1998' (CRED, 2000, p. 64).

(UNDP) Project, and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Project (CRED, 2000).

Largely due to these national programmes and international cooperation in the 1990s, the annual PV installed capacity was increased. In fact, annual growth rates of it were around 30 per cent, except in 1997 (Dai and Shi, 1999), as shown in Table VI-2. In particular, the share of agricultural and rural electrification applications was gradually increased, and thus the domestic demand for PV systems was expanded rapidly mainly because of these electrification programmes in the late 1990s. Therefore, these programmes provided the traditional PV firms with domestic market demand. However, the amount of demand was still not sufficient considering the production capacity of the traditional PV firms, JVs, and foreign firms. In fact, the annual PV installed capacity was at most 2.3 MWp in 1997 (Dai and Shi, 1999), although the production capacity was about 4.5 MWp (CRED, 2000).

Table VI-2 Annual PV installed in China, 1993-1998 (unit: kWp)

	1993	1994	1995	1996	1997	1998
Agricultural and rural electrification	270 (30%)	300 (25%)	465 (30%)	651 (30%)	920 (40%)	-
Communication	450 (50%)	720 (60%)	853 (55%)	1085 (50%)	920 (40%)	-
Others	180 (20%)	180 (15%)	232 (15%)	434 (20%)	460 (20%)	-
Total annual PV installed	900 (100%)	1200 (100%)	1550 (100%)	2170 (100%)	2300 (100%)	3000
Growth rate		33%	29%	40%	6%	30%

Source: ‘Technological Innovation of the Chinese PV Industry’ (Dai and Shi, 1999)

3.2.3.2 Accelerating R&D into PV Technology

Due to the success of economic reform, the average annual growth rate of GDP of PRC was around 10 per cent in the 1980s and 1990s (WorldBank, 2010). However, this rapid economic growth resulted in an increase in energy demand. Thus, the Chinese government made efforts to cope with a severe shortage of energy supply through: energy conservation; stepping up fossil fuels exploitation; and R&D into renewable energy. These efforts were reflected in the Sixth (1981-85) and Seventh (1986-90) Five-

Year Plans (FYPs) (NTIS, 1984; Vermeer, 1986). In particular, government funds for R&D into PV increased by more than twenty million RMB (approx. USD 7.6 million)[78] within the Sixth and Seventh FYPs (Cui *et al*., 1990).

In the Eighth (1991-95) and Ninth (1996-2000) FYPs, the funds for renewable energy reached 60 and 82 million RMB (approx. USD 9.2 and 12.6 million)[79], respectively (CRED, 2000). Research institutions, colleges, universities and PV firms conducted research into high-efficiency and low-cost solar cells, supported by this public funding. For instance, Yunnan factory participated in several science and technology programmes during the Eighth and Ninth FYPs and Kaifeng factory also undertook a series of programmes within the Sixth and Eighth FYPs (CRED, 2000).

In addition, the Chinese government formulated many R&D programmes in order to develop PV technology. In 1995, the State Planning Commission (SPC), the State Science and Technology Commission and the State Economic and Trade Commission jointly formulated 'the Development Program for China New and Renewable Energy during the Year 1996 – 2010' (CRED, 2000). Due to this programme, construction of mass production lines of poly-crystalline-silicon solar cells, upgrading of production lines of mono-crystalline-silicon solar cells and R&D into new types of high-efficiency and low-cost solar cells were carried out (CRED, 2000).

As a consequence, Chinese PV technological stock was accumulated and the laboratory efficiency of solar cells was improved, as listed in Table VI-3.

Table VI-3 Efficiency and size of solar cells in laboratories in China

Cell Type	Highest Efficiency (%)	Maximum Size
Mono-crystalline silicon	20.4 14.0	2 x 2 cm 10 cm (utility-type)
Poly-crystalline silicon	13.1 12.0	2 x 2 cm 10 x 10 cm
Amorphous silicon thin film	8.55 7.88 6.17	10 x 10 cm 20 x 20 cm 30 x 30 cm

Source: 'Commercialization of Solar PV Systems in China' (CRED, 2000)

[78] In the 1980s, the official RMB/USD exchange rate was 1.50 and 3.77 (SAFE, 2010).
[79] In the 1990s, the official RMB/USD exchange rate was 4.78 and 8.28 (SAFE, 2010).

3.2.4 Evaluation of the Traditional PV Firms

Compared with the period of the planned economy (1950s – 1978), several improvements of the PV sector were accomplished during this period (1980s – mid-1990s). Firstly, production capacity was increased and upgraded by importation of equipment from advanced foreign suppliers. Secondly, R&D cooperation between manufacturers and research institutes appeared and increased. For example, Yunnan and Kaifeng factories participated in the national projects. Thirdly, the domestic PV market grew and reached over 2MWp annual demand in the mid-1990s mainly due to the electrification programmes in northern and western provinces. Finally, some firms (for example, Yunnan factory and Harbin-Chronar Solar Power Company) started to export solar cells and modules in the 1990s (CRED, 2000).

However, compared to developed countries such as the US, Japan and Germany, the Chinese PV industry still lagged behind. Firstly, most production lines in the 1990s were out-of-date and production capacity was limited. The four mono-crystalline solar cell manufacturers still retained the same capacity and production lines which were imported in the 1980s (CRED, 2000). As a result, average photoelectric efficiency of Chinese commercialised silicon solar cells was 10-12 per cent, compared to 14-16 per cent in developed countries (Dai and Shi, 1999; CRED, 2000). In addition, the quality of solar modules was not competitive[80] in the domestic market as well as in the global market. Moreover, the production capacity[81] was not large enough to take advantage of economies of scale. Furthermore, the running rate of production capacity was around 50 per cent due to the limitations such as shortages of wafers[82]or lack of operating finance

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[80] After 3-5 years usage of some Chinese PV modules, yellowing, bubbling, delamination of contacts and an efficiency decrease happened due to the low packing quality. At that time, most of PV modules were made by hand in China (CRED, 2000).

[81] The production capacity of four mono-crystalline silicon cell manufacturers was under 1MW (CRED, 2000). It was said that economies of scale could only be achieved over 30MWp capacity at that time.

[82] ‘The equipment of most enterprises can’t form a complete system, so there is a bottleneck in the production line. Among the four monocrystalline silicon manufacturers, only the Yunnan Semiconductor Factory has an equivalent production capability between silicon and components; however, the other three factories’ capability to produce silicon is weak. The production capability of components is 1 MWp, 500 kWp, and 500 kWp in the Qinhuangdao Huamei PV Equipment Company, the Ningbo Solar Cell Company, and the Kaifeng Solar Power Source, respectively; however, their production of silicon is only 600 kWp, 300 kWp,

(Dai and Shi, 1999; CRED, 2000). Indeed, all solar cell firms had difficulty in making both ends meet and Chinese banks were reluctant to loan to solar cell firms due to their poor credit rating and the uncertainty of the solar cell market (Dai and Shi, 1999; CRED, 2000).

Secondly, in terms of the innovation approach, Chinese solar cell firms lacked access to advanced production process technology. For example, the thickness of wafers was one of the key factors in reducing production costs because it related to the amount silicon feedstock usage. Most Chinese firms used a knife cutting machine which produced wafers of about 400 μm thickness. By contrast, most foreign firms used a steel wire cutting machine which produced wafers of about 250 μm thickness (Dai and Shi, 1999). In the case of amorphous-silicon modules, Chinese manufacturers produced only single-junction modules, whilst most foreign firms produced double-junction or triple-junction modules[83] (CRED, 2000). As a result, the cost of Chinese PV modules was about 10 per cent higher than that of foreign products, despite the cost of plant construction and labour being lower than that of foreign manufacturers (Dai and Shi, 1999; CRED, 2000).

Thirdly, R&D activities were limited in terms of scale and achievements. The scale of most PV R&D projects was small because the projects depended heavily on government funding and applicants for limited R&D funds were numerous[84]. At that time, China had not established effective investment systems to support the development of high-technology. Most enterprises had to rely on self-financing in order to acquire new technology (Liu and Jiang, 2001; Allen *et al.*, 2005). However, the traditional PV firms could not afford to invest in R&D and process innovation in this period (CRED, 2000). Moreover, R&D cases were rarely successful in commercialising their R&D achievements mainly due to improper usage of R&D resources and projects being poorly organised (Dai and Shi, 1999).

Fourthly, little feedback came from the domestic market. The share of PV household

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and 150 kWp. The production capability of silicon wafers heavily restricts the ability to increase the output of PV production' (CRED, 2000, p. 60).

[83] In case of amorphous silicon modules, multi-junction modules are better in efficiency and stability than single-junction one.

[84] At that time, there were 'about 40 R&D institutions and manufacturers which were engaged in R&D on photovoltaic technology' (Dai and Shi, 1999).

systems in the domestic PV market increased gradually, as described in Table VI-2 (p. 140). However, most users were people who lived in remote and poor areas. They usually did not care about technical performance or the efficiency of the systems (Dai and Shi, 1999). Therefore, the pressure from the domestic market was not strong enough for solar cell manufacturers to improve the performance of products.

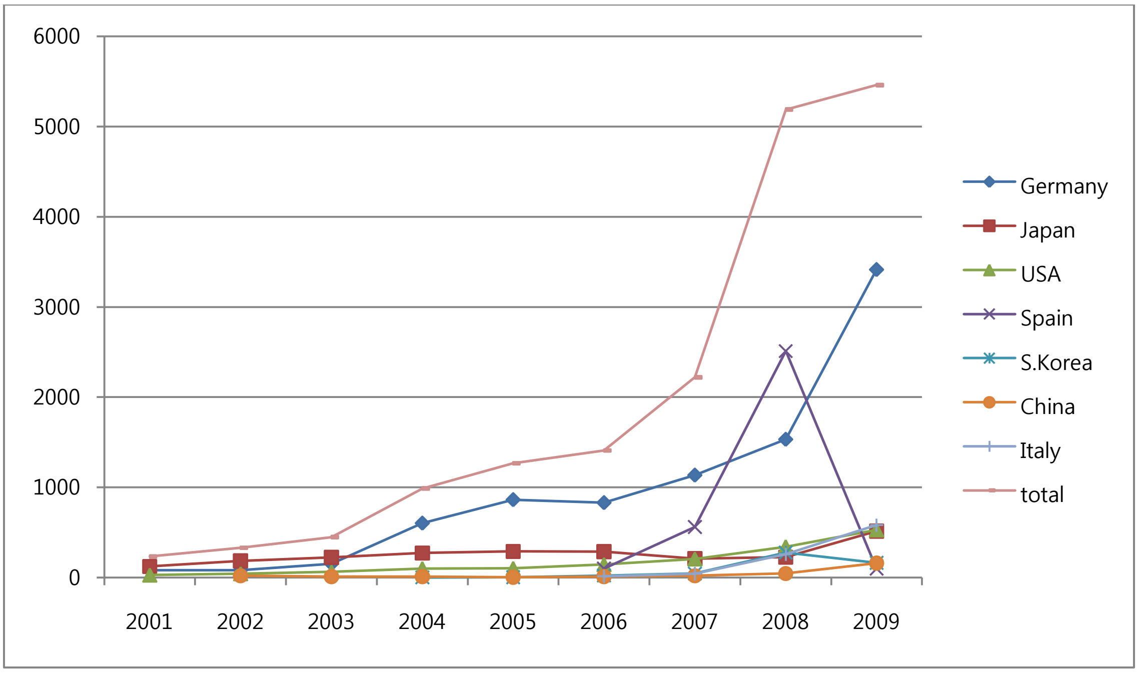
In conclusion, although the traditional PV firms had improved in some ways compared with their performance in the 1970s, they still lagged behind more advanced PV companies in aspects of production capacity and technological capability.

3.3 New Generation of PV Firms: late 1990s – 2000s

3.3.1 Growth of the Global PV Market

After the Tokyo Protocol in 1997, many countries attempted to increase renewable energy resources through various support schemes. Mainly due to adopting the feed-in tariff scheme, solar PV installed capacity was also on the rise at this time. The annual PV installed capacity can be taken to mean the demand for PV systems. As shown in Figure VI-8, the global PV demand was driven mainly by two countries: Germany and Spain (EPIA, 2010). In particular in 2004, German demand for PV soared to an annual growth rate of 294 per cent, as shown in Table VI-4. Due to the explosion of the German market, the global demand in 2004 also doubled as in 2003. Thus, after 2004, market expectations for the PV industry changed from gloomy to bright. Therefore, the uncertainty around the PV market disappeared, to some extent, through the introduction of the feed-in tariff scheme, which guaranteed a relatively long-term fixed price for PV electricity (such as 20 years in Germany). Moreover, Spain accelerated global PV demand in company with Germany in 2007 and 2008, due to its adoption of the feed-in tariff scheme.

Figure VI-8 Annual PV installed capacity of the top 7 countries (unit: MWp)



Source: 'Global Market Outlook' (EPIA, 2010)

Table VI-4 German and Spanish PV markets and growth rate (unit: MWp and %)

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Germany	81	83	153	603	863	830	1,135	1,532	3,414
		3%	84%	294%	43%	-4%	37%	35%	123%
Spain						100	561	2,511	99
							461%	348%	-96%

Source: EPIA, 2010

3.3.2 Emergence of the New Generation of PV Firms

From the late 1990s, a new generation of PV firms appeared in China, Trina Solar, which was founded in 1997, being the first. Thereafter, several PV firms, which are listed in Table VI-5 as the top 6 PV firms in China in terms of production capacity, entered into the solar cell sector and grew at an unprecedented speed and swiftly achieving the expansion of annual production capacity to over 300 MWp[85].

[85] Although there are over 100 solar PV cell companies in China in 2010 (ECJRC, 2010), I shall focus on the listed companies on Table 4 in this thesis because of the following reasons. Firstly, 300MWp is regarded as the minimum capacity to achieve economies of scale in the PV industry. Secondly, these top 6 PV firms have led the PV industry in China. They are influential in China's PV industry from the point of view of technological capability as well as production capacity. Although Ningbo factory has over 300MWp production capacity (ECJRC, 2009), its main features are very different from the new generation PV firms. For example, its corporate

Table VI-5 Entry of the new generation of PV firms in China

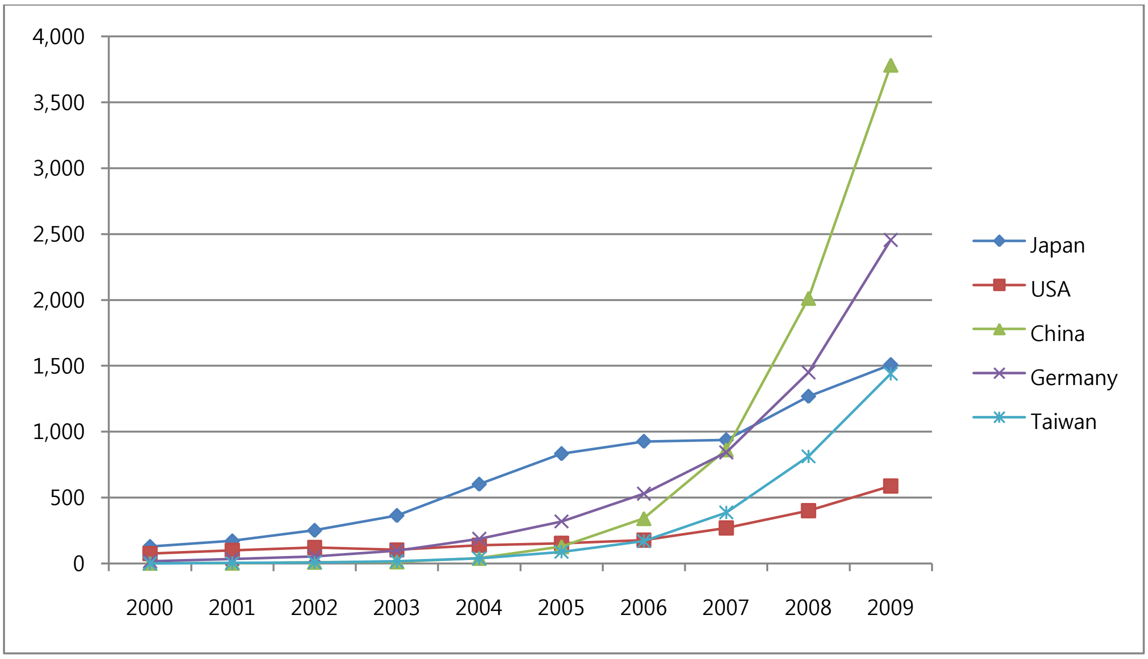
Name	The year of establishment	Product capacity in 2009 (unit: MWp)
Trina Solar	1997	600 (ingot, wafer, cell, module)
Yingli	1999	600 (polysilicon*,ingot, wafer, cell, module)
Suntech	2001	1,100 (cell, module)
Solarfun	2004	420 (ingot, wafer, cell, module)
China Sunergy	2004	320 (cell)
JA Solar	2005	875 (cell, module)

Source: Each company's web sites, 'PV Status Report' (ECJRC, 2009), and interviews

*Yingli's subsidiary company, Fine Silicon, started a trial produced silicon feedstock in 2009.

Due to the rapid growth of the new generation of PV firms, China has been ranked as the largest manufacturing country of PV in the world since 2008 surpassing Japan, as shown in Figure VI-9. Furthermore, four Chinese PV firms were ranked in the top 10 manufacturers in the world at the end of 2009. Table VI-6 shows us this.

Figure VI-9 PV production of the top 5 countries (unit: MWp)



Source: BSW, 2009 and 2010; Roney, 2010; KNREC, 2009

governance is still state-owned and its marketing directs more to the domestic market than to the global market. Thus, Ningbo factory can still be categorised as a traditional PV firm. Henceforth, the new generation of PV firms can be taken to mean the top 6 PV firms, unless otherwise stated.

Table VI-6 Top 10 solar cells manufacturers in the world at the end of 2009

Rank	Name	Nationality	Annual production of solar cells (MWp)
1	First Solar	The US	1,100
2	**Suntech**	**China**	704
3	Sharp	Japan	595
4	Q-Cells	Germany	586
5	**Yingli**	**China**	525
6	**JA Solar**	**China**	520
7	Kyocera	Japan	400
8	**Trina Solar**	**China**	399
9	Sunpower	The US	397
10	Jintech	Taiwan	368

Source: Photon International (April 2010)

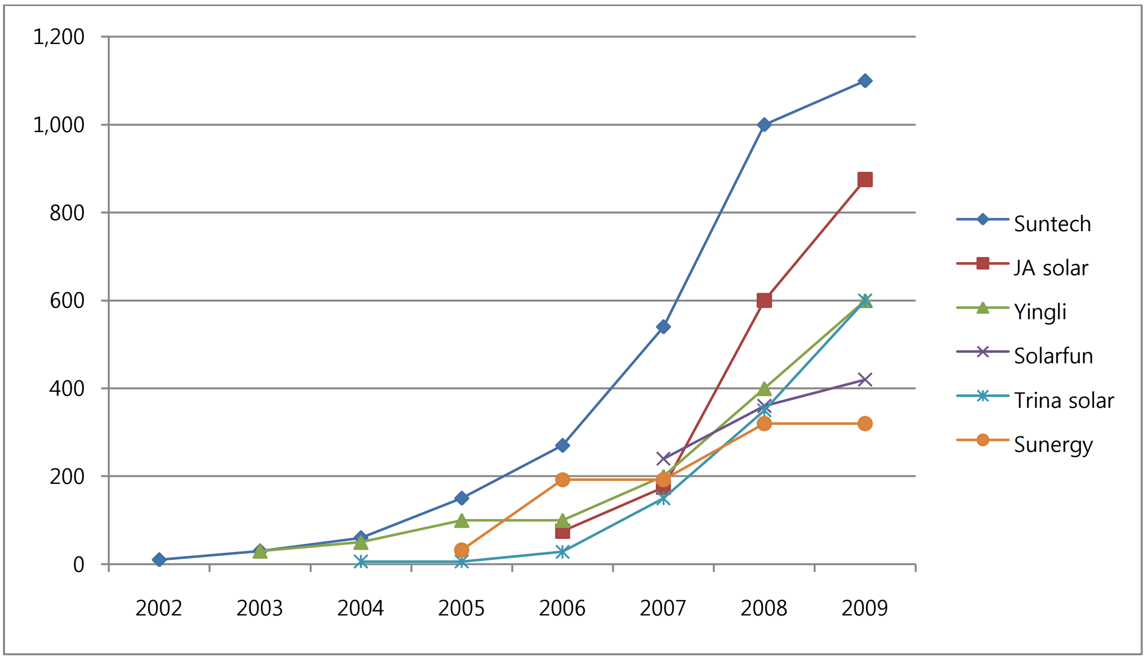
This astonishing rise of the Chinese PV industry is on a par with other Chinese industries such as the marine container and personal computer sectors (Zeng and Williamson, 2007). How did this take place? What are the differences between the traditional PV firms and the new generation of PV firms? How did Chinese PV firms expand their production capacity faster than any other country? How did the Chinese PV sector acquire technological capability at a high enough level to compete with those of advanced countries? What were the roles of governments in these processes? These are key questions in explaining a success story of the PV industry in China.

In order to answer these questions, I conducted field work in China in July, 2010. As part of this field work, I interviewed 9 firms, of which 6 were new generation PV firms. I also spoke to 1 policy maker and 5 experts who are involved in the Chinese PV industry. Hereafter, this chapter will be based on the interviews carried out during this field work.

3.3.3 Rapid Expansion of Production Capacity

In the late 1990s, crystalline-silicon solar cell technology became mature compared to thin film and organic solar cell technologies (Green, 2000). It has been said that expanding production capacity quickly in order to achieve economies of scale is the best strategy to success in the PV industry (KPMG, 1999). In fact, the new generation of PV firms followed this strategy. As shown in Figure VI-10 and Table VI-7, total production capacity of these six firms started under 10 MWp in 2002 and reached around 4,000 MWp at the end of 2009. Most of them expanded their production capacity annually.

Figure VI-10 Production capacity of the top 6 PV firms in China (unit: MWp)



Source: Annual reports and web sites of each firm and interviews

Table VI-7 Production capacity of the top 6 PV firms in China (unit: MWp)

	2002	2003	2004	2005	2006	2007	2008	2009
Suntech	10	30	60	150	270	540	1,000	1,100
JA solar					75	175	600	875
Yingli		30	50	100	100	200	400	600
Solarfun						240	360	420
Trina solar			6	6	28	150	350	600
Sunergy				32	192	192	320	320
total	10	60	116	288	665	1,457	3,030	3,915

Source: Annual reports and web sites of each firms and interviews with them

3.3.3.1 Local Governments and Institutions

In terms of corporate finance, the expansion can be divided into two different stages: one is an initial investment stage by 2004; the other is an initial public offering (IPO) stage in the foreign stock market after 2005. The first stage was a very difficult time for the PV firms to invest, because the size of the global market was small, and the rate of growth slow, as shown in Figure VI-8 (p. 144). In other words, the PV industry was regarded as too risky to invest in before 2004. Interviews (Chen, 2010; Xu, 2010; Wei, 2010) and literature (Park, 2009) show the difficulties, the new generation of PV firms faced at this time as follows:

> Suntech built a 10 MWp production capacity in 2002, and then Dr. Zengrong Shi, the CEO, tried to expand it to 30 MWp in 2003. At this time, most of high executive officers and major stockholders objected to his expansion plan, because PV markets were uncertain and the performance of the firm was not good. Sometimes, salaries for high executive officers and engineers were not paid by the firm. Thus, some engineers quitted the firm. But, he convinced Wuxi City (*shi*) government and induced local state-owned companies to invest in his firm. Thus, mainly due to the financial support from the local government and SOEs, Suntech completed a 30 MWp production capacity in 2003 (Chen, 2010).

Also, other firms' initial investments were supported financially by bank loans and SOEs' investments under the assistance of the local government. In short, local governments supported the new generation of PV firms in a range of ways such as, encouraging local state-owned companies to invest in them and guaranteeing them for bank loans.

Considering the active role of local governments in the initial investments; why did Chinese local governments get heavily involved in these investments and the growth of these industries, despite their risky nature? One of the answers to the question can be found in the characteristics of the Chinese institutional framework, so called 'local state corporatism' (Oi, 1999), as I discussed earlier (p. 17). Chinese local governments have strong incentives to facilitate the growth of local industries due to fiscal decentralisation and the evaluation system of cadres and high officials (Arrighi, 2007). The PV industry was one of the beneficiaries of this kind of functional industrial policy of local governments. In fact, Yingli and Solarfun have become the biggest firms in Baoding City (*shi*) and Qidong County (*xian*), respectively. Suntech has become the second biggest firm in Wuxi City (*shi*). In short, most of city governments in Jiangsu Province have strongly supported PV firms in their localities (Suntech in Wuxi, Trina Solar in Changzhou, China Sunergy in Nanjing, and Solarfun in Nantong) (Wei, 2010). Furthermore, because the PV industry was regarded as a high-tech[86] and green technology industry, it received greater preferential treatment compared to other industries by local governments. Mainly due to the support by city (*shi*) governments, banks, and local SOEs, most of the new generation of PV firms could achieve a basic size of production capacity in readiness for the next stage of rapid growth.

3.3.3.2 Foreign Stock Markets

After the explosion of demand for PV in 2004, in the second stage, investors' expectations of future PV markets brightened. On the basis of experience and readiness in the first stage, the new generation of PV firms accelerated their investments in response to this optimistic signal about future markets. In order to raise more funds rapidly, they entered into the foreign stock market guided by returnees and overseas Chinese who knew the global finance market well (Xu, 2010). Suntech led this trend through its IPO on the New York Stock Exchange (NYSE) in 2005, and other Chinese PV firms followed Suntech's example. In 2006, Trina Solar and Solarfun were listed on the NYSE and Nasdaq, respectively. In 2007, Yingli followed suit by joining the NYSE, while JA Solar and China Sunergy were listed on Nasdaq. Thus, all of them were listed on stock markets in the US. Tapping into overseas capital pools enabled them to expand their production capacities very rapidly so that they could achieve economies of scale. As a consequence, their total production increased at an unprecedented rate in the second stage as illustrated in Figure VI-10 (p. 148).

Global financing through the foreign stock market is another distinctive feature in the growth of the PV industry in China. However, this new trend of financing came into

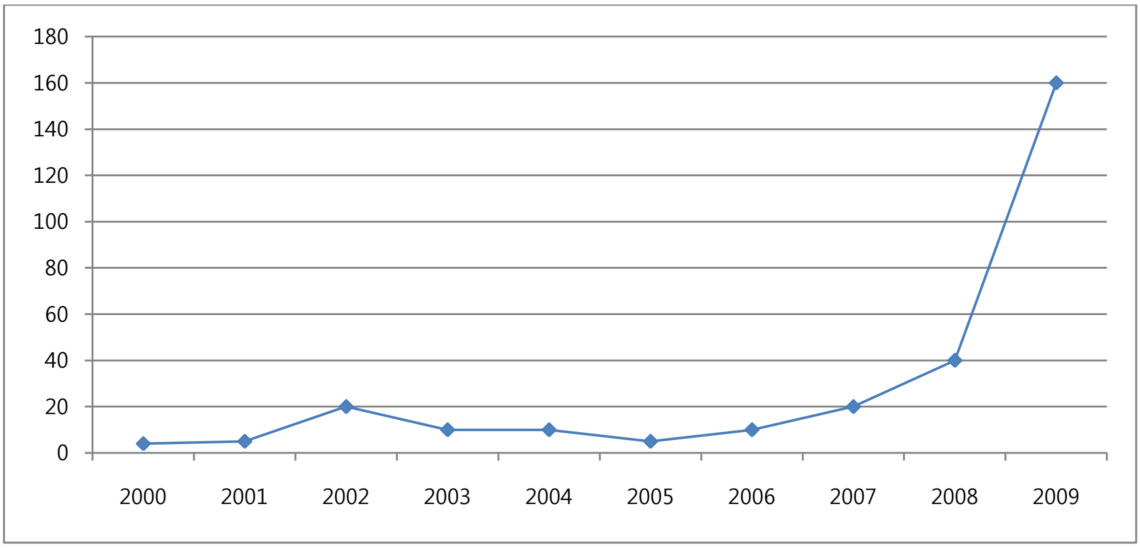
[86] At the central government level, there were many special supports for technology-based firms such as grants, low-interest loans, tax incentives, and high-tech zones (Marigo, 2009)

fashion not only in the PV sector but also in other sectors in China in the 2000s. Indeed, since China joined the WTO in 2001, Chinese firms have been able to access foreign stock markets more easily than ever before. In fact, the total worth of Chinese firms' IPOs on the foreign stock market was 20.5 and 44.0 billion USDs in 2005 and 2006, respectively (Park, 2009). Thus, it can be inferred that an institutional change in financing through foreign stock markets also influenced the Chinese PV sector. In other words, access to the foreign stock market enabled the new generation of PV firms to expand their production capacities very rapidly in the second half of the 2000s.

3.3.4 Export-led Growth

Although PV production increased rapidly in China in the 2000s, the domestic PV market still grew slowly due to the lack of strong incentive systems like the German feed-in tariff scheme, as shown in Figure VI-11. In fact, China produced around 3,800 MWp of PV modules but consumed only 160 MWp locally in 2009.

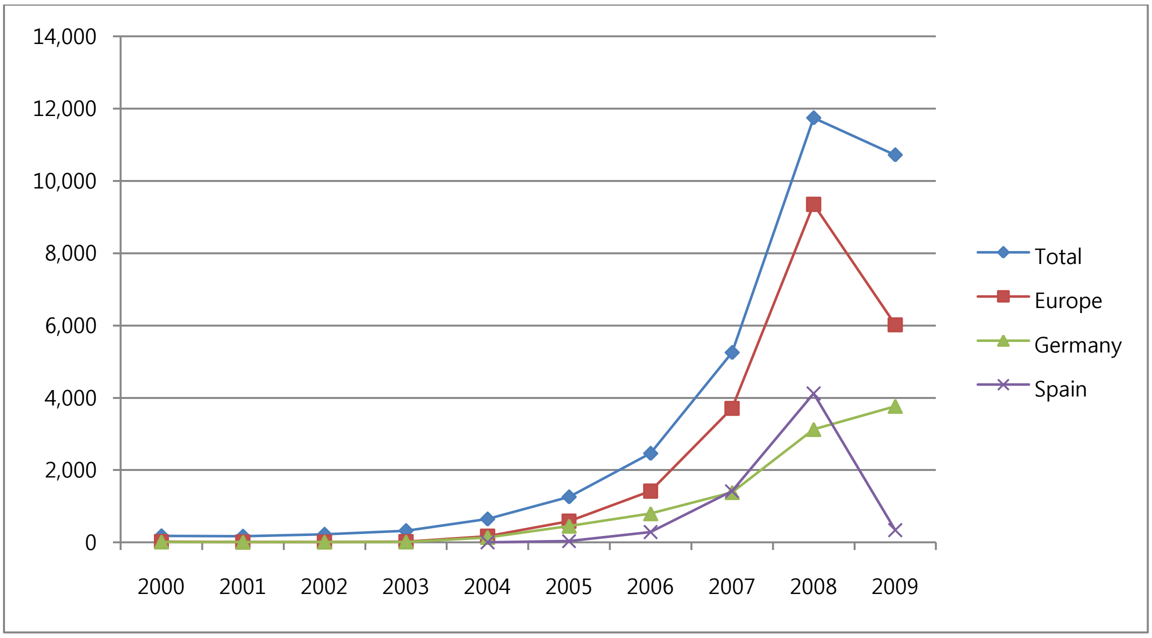
Figure VI-11 Annual PV installed in China in the 2000s (unit: MWp)



Source: EPIA, 2010

This means that almost all PV modules were exported to foreign countries. PV trade data in China reveals this to be true. As shown in Figure VI-12, the European market has played a substantial role in the growth of the Chinese PV industry in the 2000s. Their import accounted for around 80 per cent of PV exports in China at this time (except in 2009).

Figure VI-12 PV products export in China (unit: USD million)



Source: UN COMTRADE database

Through the export-led growth, the new generation of PV firms has overcome 'two sets of competitive disadvantages' of latecomer firms (Hobday, 1995). Firstly, they made efforts to learn state-of-the-art technology through various routes, in order to export their products to international markets. This is examined in the next sub-section. Secondly, they were able to access the sophisticated demand of the global market so that they were not isolated from mainstream international markets. Finally, they were able to meet sufficient demand to achieve economies of scale through exports.

However, exporting to the advanced foreign countries was not easy for Chinese PV firms. At the start, it was very difficult for them to penetrate the European PV market. Thus, they focused on attaining certificates of European countries such as TÜ V and IEC (Chen, 2010), because solar systems required a long-term guarantee such as 25 years. As time went by, they succeeded in building marketing networks and letting European customers know their own brand names mainly through their credible and cheap products (Lee, S., 2010). In terms of cost advantage, as I discuss later, the price of their products was around two thirds that of foreign companies' products.

3.3.5 Technological Learning

As in the East Asian catching-up processes (Hobday, 1995), technological learning for the new generation of PV firms was conducted through various channels such as turn-key based importation of capital goods, learning by manufacturing, and original equipment manufacturing (OEM) (Lee, S., 2010; Chen, 2010). In particular, there were two main types of technological learning: codified knowledge was learned mainly by importation of equipment and learning by manufacturing; tacit knowledge was introduced by scientists who studied abroad and engineers who worked for the traditional PV firms.

Firstly, because crystalline-silicon solar cell technology matured, most state-of-the-art technologies were embedded in production equipment by the 2000s (Bae, 2009). Thus, importation of equipment from advanced foreign suppliers was one of the best ways to learn state-of-the-art technology. In fact, the new generation of PV firms learned how to install equipment, how to modify equipment in order to reduce production costs, and finally how to make equipment through continuous expansion (Lee, S., 2010; Chen, 2010). Indeed, they expanded their production capacities almost every year.

According to interviews (Lee, S., 2010; Chen, 2010; Xu, 2010; Zhu, 2010; Sun, 2010; Yang, 2010), technological learning through equipment can be summarised as follows. At first, they all imported turn-key based equipment from more advanced countries such as Germany, the US, and Japan. As time went by, they could select the best equipment in each production process piecemeal and install it by themselves. As the volume of domestic demand for PV equipment grew, local equipment suppliers emerged in simpler PV equipment markets. They collaborated with these local equipment suppliers who were able to provide them with lower-priced equipment. Recently the market share of the Chinese equipment industry reached around 50 per cent of the local PV equipment market (Chen, 2010; Sun, 2010). Thus, using local equipment partly contributed to the rapid growth of production capacity in that it enabled them to reduce expansion costs.

Secondly, technological learning was led mainly by scientists who studied state-of-the-art PV technology in foreign countries. This point is one of the most distinctive features of the catching-up process of the Chinese PV industry. Dr. Zhengrong Shi, who is the founder and CEO of Suntech, is the most famous example of this kind of PV scientist (Chen, 2010; Wei, 2010). Table VI-8 shows us how many scientists who studied abroad work in top management positions.

Table VI-8 Scientists and technicians in the top management group

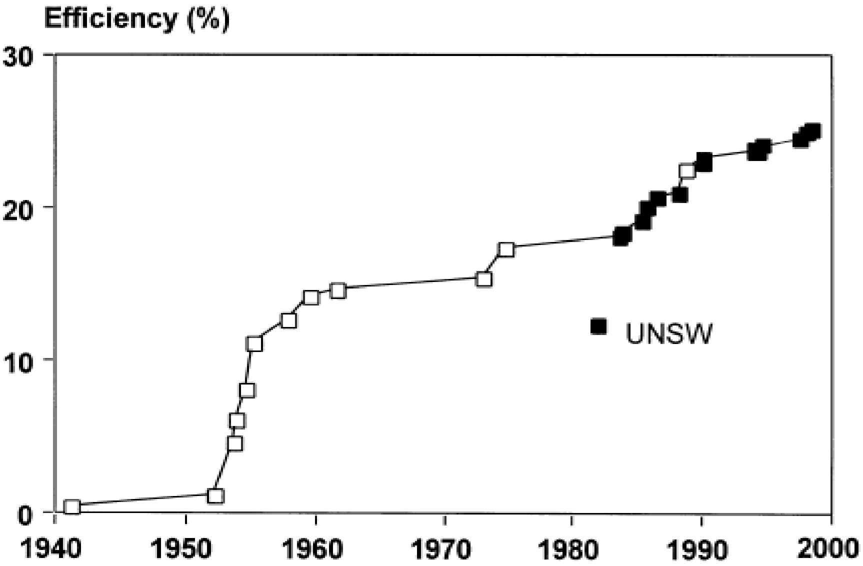
	Scientists (position/career/year of PhD)	Technicians (position/career)
Suntech	Zhengrong Shi (CEO/UNSW/'92) Jingjia Ji (Senior Researcher/UNSW/'94) Guangchun Zhang (Researcher/UNSW) Stuart Wenham (CTO/UNSW/'86) Graham Artes (COO/Kuttler)	Some technicians (high position engineer/Yunnan)
Yingli	Guaxiao Yao (CTO/UNSW/'95) Seok Jin Lee (COO/HII) Nabih Cherradi (VP/France)	
Trina Solar	Qiang Huang (VP/Singapore) Suping Chen(VP/China)	Sean Hsiyuan Tzou (COO/US) Chen Chung Yu (VP/Taiwan) Yu Zhu (VP/US) Diming Qiu (Senior Researcher/Yunnan)
China Sunergy	Jianhua Zhao (CTO/UNSW/'89) Aihua Wang (VP/UNSW/'92) Fengming Zhang (VP/Australia/'96)	
JA Solar	Ximing Dai (CTO/UNSW/'95) Bingyan Ren (Director/China)	Zhilong Zhang (COO/China) Boping Li (VP/China)
Solarfun	Yun Fei (Researcher/UNSW)	Yuting Wang (CE/Qinhuangdao)

Source: Annual reports of each firm and interviews with them

CEO (Chief Executive Officer); CTO (Chief Technology Officer); COO (Chief Operating Officer); VP (Vice President); CE (Chief Engineer); UNSW (University of New South Wales in Australia); Kuttler (German equipment company); HHI (Hyundai Heavy Industries, Korean company)

Two interesting facts can be identified in Table VI-8. One fact is that over half of these top management scientists are from the University of New South Wales (UNSW), Australia. Indeed, the centre for PV engineering in the UNSW has achieved a world record in efficiency of crystalline-silicon solar cells since the late 1980s, as shown in Figure VI-13. Most of these scientists worked in this centre, which was led by Professor Martin A. Green, who was a Nobel Prize laureate in 2002. Thus, most of them had good knowledge of cutting-edge PV technology and were able to play a key role in technology transfer in the PV sector in China.

Figure VI-13 Evolution of the efficiency of silicon cells in laboratories



Source: Green, 2000, p. 992

The other fact is that innovation was often accomplished by a combination of these scientists and technicians who had experience in traditional PV firms (Chen, 2010; Zhu, 2010). These two groups seem to have possessed a complementary relationship in terms of innovation. Usually, scientists have good knowledge of state-of-the-art technology and laboratory-level experiments, but can lack experience of manufacturing. In contrast, technicians who have worked in factories for a long time have a lot of tacit knowledge of mass production, but know little of new technologies. According to Table VI-8, there were some technicians from traditional PV firms such as Yunnan and Qinhuangdao factories. It seems, therefore that this combination is likely to have worked well. There is no direct evidence of this kind of innovation, however, indirect evidence is provided by the fact that the technicians worked in important positions in the new generation of PV firms (Chen, 2010; Zhu, 2010; Yang, 2010).

In addition, ‘complementary assets’ (Teece, 1986) of the PV industry can be found throughout the Chinese economy. The machine tools industry, the semiconductor industry and the electronics industry were developed adequately to support the developing PV industry in the late 1990s (Chen, 2010). Moreover, abundant human resources were involved in PV technology at that time (Chen, 2010).

Another factor is that, M&As have increased in China since joining the WTO and have acted as one of the channels for accessing state-of-the-art foreign technology. In the PV sector, Suntech acquired MSK Corporation, a leading PV module manufacturer and Building-Integrated PV (BIPV) company in Japan in 2006, and KSL-Kuttler, a German company specialising in equipment automation in the printed circuit board industry in 2008. Due to the M&As, Suntech has been able to accelerate its innovation in this area.

In short, various types of technological learning enabled the new generation of PV firms to reach a similar technological level to more advanced foreign PV companies.

3.3.6 Cost Advantages

One of the most important comparative advantages of Chinese companies is cost advantage. First of all, labour costs are cheaper than any other country considering the quality of labour. Average salary of workers in the industrial sector was 26,599 RMB/year (approx. 3,900 USD)[87] in 2009 (NBSC, 2010). In fact, the salary of workers in the PV factories was between 1,000 and 1,500 RMB (approx. 146 and 220 USD[88]) a month in Jiangsu Province in 2009 (Lee, S., 2010). Thus, some production processes such as welding and arraying of solar cells in the module production process are still conducted by workers, as shown in Figure VI-14.

Figure VI-14 Manual production processes: welding and arraying

[87] In China, average salary of workers is substantially different between provinces. For example, it was 48,207 RMB/year in Shanghai, 40,642 in Beijing, 27,372 in Jiangsu Province, and 23,815 in Hebei Province in 2009 (NBSC, 2010).

[88] In 2009, the official RMB/USD exchange rate was around 6.83 (SAFE, 2010).

Source: Xu, 2009

The manual process is argued to give two advantages to Chinese firms. One is cost-effectiveness compared to the automated process. In terms of breakage of solar cells in the production process, Chinese PV firms train their workers and introduce a penalty system which connects worker's breakages to his or her salary (Lee, S., 2010; Chen, 2010; Zhu, 2010; Xu, 2010). Therefore, it is argued that the rate of breakage in the manual process is lower than that of the automated process (Xu, 2010; Zhu, 2010). The other is an advantage of customisation. Customisation strategy is important in the PV sector, because there is demand for different sizes of PV modules. The cost of customization in production using the manual process is much lower than that of the automated process. This kind of cost innovation appears not only in the PV sector but also in the electronics sector in China (Zeng and Williamson, 2007).

Secondly, low R&D costs are another advantage of Chinese PV firms. The traditional PV firms and many local universities have supplied them with skilful human resources at low wages. For example, a high positioned engineer, working for Suntech, originally worked at the 'Yunnan factory' at a monthly salary of around 2,000 RMB[89] (approx. 300 USD[90]) in the 1990s (Chen, 2010). With regard to the higher education system, this is mainly because the tertiary education system focuses on science and engineering subjects in China. In fact, more than 300,000 scientists and technologists graduated from universities and these degrees accounted for 73 per cent of the total of first university degrees awarded in China in 2002 (National Science Board, 2002 cited in Marigo, 2009). Indeed, the average initial salary of Master degree engineers in the PV

[89] Of course, now his salary is much more than this.
[90] In the 1990s, the official RMB/USD exchange rate was between 4.78 and 8.28 (SAFE, 2010).

industry is around 3,000 RMB (approx. 430 USD) a month. Thus, quality control in production processes and in-house R&D were available at a lower cost in China than in foreign countries. In addition, collaborations between the new generation of PV firms and local universities and domestic research institutes such as Shanghai Jiatong University, Sun Yat-sen University, and the Chinese Academy of Science have increased and contributed to facilitating innovation at low cost (Zhu, 2010; Xu, 2010).

Thirdly, the cost of production capacity expansion of Chinese PV firms was cheaper than that of foreign companies. It is argued that the setting cost of a 25 MWp production line with mixed local and foreign equipments was around half that of foreign companies (Wang, 2010). Moreover, local governments sometimes provided them with land preferentially. As a consequence, they were able to expand production capacity cheaply and rapidly compared to foreign companies.

Partly due to these cost advantages, the Chinese PV products could penetrate the global market, as I describe in sub-section VI.3.3.4.

3.3.7 Vertical Integration Strategy

In the crystalline-silicon solar PV industry, the value chain is composed of four sub-industries: poly silicon (raw material), ingot and wafer (components), cell (components), and module (finished goods) sub-industries. In terms of a vertical integration strategy, cell and module industries are the starting points for vertical integration of the whole value chain. However, manufacturing processes of PV modules are simpler and more labour-intensive than those of PV cells. Moreover, a technological entry barrier of the cell industry is higher than that of the module industry.

Almost all the PV firms that I interviewed adopted a ‘vertical integration’ strategy except JA Solar. This strategy secured the PV firms raw material and components and gave them room for reducing production costs in terms of transaction costs (Williamson, 1971). Yingli, Trina Solar, and Solarfun started as module assemblers and integrated backwards through the value chain. These firms chose to begin with module assembly because they were less technically oriented than Suntech and China Sunergy in the initial stage. However, later on, they learned and assimilated technology, and internalised from ingot and wafer production to cell production. Finally, Yingli completed the whole value chain from poly silicon to solar modules in 2009.

By contrast, Suntech and China Sunergy started as a cell supplier and integrated forward through the value chain. At first, they began with solar cell manufacturing because their founders, Dr. Zhengrong Shi and Dr. Jianhua Zhao, were experts in the latest solar cell technology. Over time, they extended their firms' boundaries to module production in order to reduce transaction costs.

In short, vertical integration of the new generation of PV firms was one of the strategies that allowed them to establish their competitive advantages.

3.3.8 Role of the Central Government

As I describe in sub-section VI.3.2.3 (p. 139), the central government encouraged research and development of PV technology and formulated many demand-pull programmes. In line with these electrification programmes, the central government started the 'Transmission Electricity to Village (*Song Dian Dao Xiang*)' programme in the early 2000s. Due to this programme, the new generation of PV firms such as Trina solar and Yingli accumulated their experiences and managed to maintain their production capacity without exporting their products to the global market (Wei, 2010; Yang, 2010).

With regard to the feed-in tariff scheme, a Renewable Energy Law was passed in 2005 and has been effective since 2006. Although this law has provisions similar to the German feed-in tariff, the feed-in tariff is not yet implemented in China (CREDP, 2008; EPIA, 2010). According to interviews, a local feed-in tariff has been implemented in Jiangsu Province, but the scale is very limited (Wei, 2010; Zhu, 2010).

After the global financial crisis in 2008, the demand for PV in the global market shrank, causing difficulties for the Chinese PV industry. In 2009, the central government (the Ministry of Finance, the Ministry of Science and Technology, and the National Energy

Administration of the National Development and Reform Commission) launched 'the Golden Sun (*Jin Tai Yang*) Project' which was to facilitate the deployment of large-scale PV plants of no less than 500 MWp within the coming two or three years (MOST, 2009). This programme has helped partly to overcome the aftermath of the financial crisis for the PV firms as well as to accomplish the renewable energy target of the central government.

4. IMPACT OF INSTITUTIONAL ADVANTAGE ON THE NECESSARY FUNCTIONS

As in the German chapter (V), in this section, I shall examine the inter-relationship between the institutional advantage of the Chinese political economy and the four necessary functions in the development of the Chinese PV industry: market formation; capital mobilisation; process innovation; and cost reduction.

4.1 Market Formation

The Chinese government implemented a series of electrification programmes, installing PV systems in rural areas in the 1990s, as described earlier (p. 139). Also, the 'Transmission Electricity to Village (*Song Dian Dao Xiang*)' programme was carried out in the early 2000s. These government programmes increased domestic demand for PV systems. In particular, *Song Dian Dao Xiang* helped some PV firms survive during difficult times.

However, the amount of PV demand created by the Chinese government's demand-pull policy was not enough to satisfy the Chinese PV industry. Furthermore, despite the Renewable Energy Law, the feed-in tariff was not yet implemented in China. Thus, in contrast to the German case, there was no substantial domestic market creation for the PV industry in China. In other words, in terms of market creation, China had an institutional disadvantage compared to Germany.

In the German case, due to the creation of the domestic PV market, the domestic PV industry grew fast throughout the 2000s (see p. 111). However, in the Chinese case, the domestic PV industry grew fast without the creation of an adequate domestic PV market in the 2000s. As far as China is concerned, it is clear that the creation of a domestic PV market was not a necessary condition for the development of the domestic PV industry. Thus, it can be said that the Chinese PV industry was able to grow despite the institutional disadvantage in terms of market creation.

4.2 Capital Mobilisation

In order to achieve economies of scale rapidly, capital mobilisation was a key factor because the crystalline-silicon cell industry was capital-intensive. China had an institutional advantage in mobilising capital through an unprecedented combination of local state corporatism and global financing during the 2000s.

In the early 2000s, local governments, especially city (*shi*) governments, played a decisive role in mobilising capital in the PV sector. At this time, the Chinese PV industry was too risky for investors, because the domestic PV market was not sufficient to demand large scale PV production. Moreover, it was difficult for the Chinese PV industry to penetrate the global PV market due to the low quality and high price of its products. However, local governments facilitated the new generation of PV firms in raising funds through various routes, because they had a strong incentive to encourage local industries in their localities, as discussed in sub-section VI.3.3.3.1 (p. 149).

After 2005, global financing paved the way for the Chinese PV industry to tap into a huge pool of foreign capital. After Suntech succeeded in mobilising capital in the New York Stock Exchange in 2005, the rest of the new generation of firms imitated Suntech’s success. As a consequence, the influx of a substantial amount of capital from the foreign stock market enabled the Chinese PV industry to expand its production capacity at an unprecedented rate. Thus, China has become the largest PV manufacturer since 2008.

Compared to the German case, different financial mechanisms have played a part in mobilising capital in the PV industry in China, local state corporatism and global financing in particular have been unique institutional instruments in mobilising capital for the development of China’s PV industry.

4.3 Process Innovation

Compared with leading countries in the PV sector such as Germany, the US and Japan, China lagged far behind in terms of technology in the 1980s and 1990s. Thus, technological learning was a major issue for the Chinese PV industry. According to Hobday (1995), a range of institutional mechanisms functioned as channels of technology transfer from more advanced countries to East Asian ones, as discussed in sub-section II.2.3.2 (p. 22). In the technological learning process of the Chinese PV industry, two factors played a key role in catching up with forerunner countries. One was the importation of state-of-the-art equipment and learning by manufacturing, and the other was the coming together of scientists who studied abroad and engineers who worked for the traditional PV firms.

Firstly, mainly codified knowledge was transferred by the former mechanism in that cutting-edge c-Si cell technology was embedded in production equipment. The new generation of PV firms imported sets of PV equipment, assimilated production processes using the equipment, and modified the production processes (Marigo, 2009). The speed of learning by manufacturing was fast, because learning was much faster in the factory than in the laboratory (Lee, S., 2010; Peschke, 2010).

Secondly, returning scientists and experienced engineers took a lead in the process of learning by manufacturing. The scientists knew about new PV technologies, whereas the engineers knew much about the floor experience of mass production. Thus, they played complementary roles in production processes using their tacit knowledge.

In short, these two mechanisms enabled the Chinese PV industry to catch up with more advanced countries in terms of process innovation.

4.4 Cost Reduction

It is difficult to deny that China has an explicit comparative advantage in labour-intensive sectors, because it has a large fund of labour available. Not only labour-intensive sectors such as the textile industry but also the PV industry has benefited from a labour-cost advantage despite being a capital-intensive industry[91]. For instance,

[91] The implications of this are different from the comparative advantage theory. According to this theory, a relatively labour abundant country has a comparative advantage in labour-intensive sectors not in capital-intensive sectors.

machines have been replaced by workers in some processes such as welding and arraying cells because of the cost-effectiveness of manual labour, as mentioned in sub-section VI.3.3.6 (p. 156).

Both low labour cost and low R&D costs have provided the PV industry with an overall cost advantage. In fact, the average initial salary of a Masters degree engineer in the PV industry is around 3,000 RMB (approx. 430 USD) a month. This is mainly because the Chinese higher education system supplies a huge number of scientists and engineers for industries. Most of their R&D activities are involved in quality control and process innovation not in product innovation such as the development of a new product.

Furthermore, low expansion costs of production capacity are one of the cost advantages of the Chinese PV sector. Low prices for production equipment supplied by the local machinery industry, low land costs, and low construction costs have all contributed to the low expansion costs of the PV industry in China.

Owing to these cost advantages, the price of cells and modules of the Chinese PV industry have been able to be lower than any other country, making Chinese solar cells and modules competitive in the global market.

5. CHAPTER SUMMARY

In this chapter, I have explained the evolution of the PV industry, and impacts of institutional advantage on the evolution, in the context of the political economy of China.

After economic reform in 1978, a market mechanism was introduced into the Chinese economy and the traditional PV firms appeared. They upgraded their production facilities, but they fell far behind more advanced countries. There was no remarkable improvement in the PV industry in China until the emergence of the new generation of PV firms in the late 1990s.

Between the late 1990s and the early 2000s, the new generation of PV firms succeeded in mobilising capital with support from local governments despite it being a very risky time to invest. Due to the market explosion in Europe, they grew fast through exports without substantial domestic market creation. Furthermore, after China joined the WTO, they raised funds through tapping into the foreign stock markets. As a consequence, they expanded their production capacities faster than in any other country.

In addition, in terms of technology, they caught up with leading companies mainly through importation of equipment from more advanced countries and a successful linking up of scientists who had studied abroad and engineers who had worked for the traditional PV firms. With regard to cost reduction, China’s cost advantages make the PV industry more competitive than in any other country. Thus, it can be said that the Chinese PV industry does not lag behind more advanced countries any longer in terms not only of production capacity but also of technology and cost.

CHAPTER VII PV INDUSTRY IN KOREA

1. INTRODUCTION

The aim of this chapter is to examine the relationship between the Korean political economy and the evolution of the Korean PV industry and to investigate institutional advantages and disadvantages of the Korean economy related to the development of the PV industry. Thus, I shall focus on three drivers[92] (market formation, capital mobilisation and process innovation) in the Korean context and their impact on the development of the PV industry. The key questions are as follows: firstly, why the policy regime, especially the feed-in tariff, failed to facilitate the development of the PV industry in Korea unlike Germany; secondly, under what context of the political economy the policy regime was formulated and why Korea was late in starting its PV industry: thirdly, what institutional configuration of Korean political economy affected this evolution.

Given the assumption that a sector is embedded in a political economy, the policy regime for the PV sector has been formed and Korea's PV industry has evolved under the influence of the Korean political economy. Thus, it is necessary to begin with an exploration of the political economy of Korea.

Firstly, in section 2, I shall explain the history of the Korean political economy. Between the 1960s and 1980s, Korea succeeded in industrialising its economy as an example of a developmental state. However, since the 1990s, liberalisation of the economy has been started. In particular, before and after the 1997 crisis the developmental-state characteristics of the Korean political economy were dismantled.

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[92] It is difficult to access cost information of the Korean PV firms, mainly because most of them have started PV cell businesses since 2008. Furthermore, SMEs (Photon Semiconductor, Millinet Solar and Shinsung Holdings) of them do not need to publish their annual reports, because they are not listed on the stock market. Thus, the Korean PV industry is not analysed in terms of cost reduction.

Secondly, in section 3, I shall examine the evolution of the Korean PV industry. After the two oil shocks the National Project was implemented in order to develop PV technology. However, due to the limitation of technological capability, commercialisation of the first production facility failed. In 2002, the feed-in tariff was adopted by the collaboration between an environment-oriented coalition and an industry-oriented coalition. As a result, the domestic PV market expanded enough to stimulate the local PV industry to grow. However, it was not a good time for local firms to invest in the PV sector. In fact, *chaebols*, large Korean business groups, responded to the market expansion late because they had little opportunity to find new businesses under the restructuring programme in the early 2000s. Thus, the domestic market was penetrated largely by imported solar modules. Eventually, the feed-in tariff was changed to the less supportive policy scheme, the Renewable Portfolio Standard, and Korea's PV industry fell behind the other leading countries such as Germany and China.

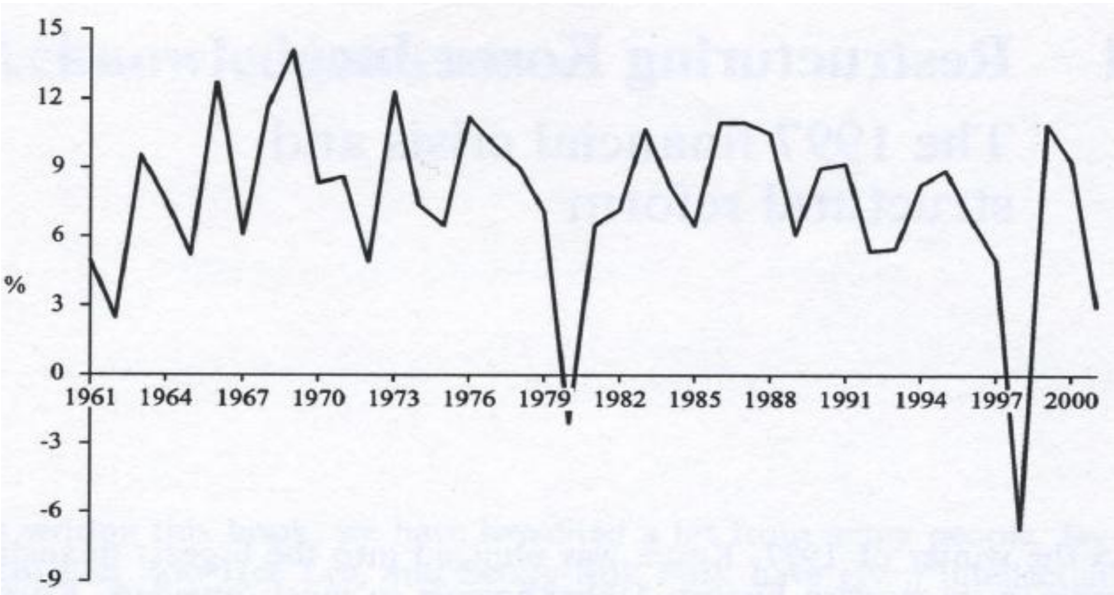
Lastly, in section 4, I shall attempt to explain the inter-relationships between institutional advantage of the Korean economy and the development of the PV industry. Despite the institutional advantage of the growth of the local PV market, the Korean PV industry failed to catch up with leading countries mainly due to the institutional disadvantage in mobilising capital in new sectors.

2. POLITICAL ECONOMY OF KOREA

2.1 The Success of Korea: Free Market versus Developmental State

Korea has been one of the fastest growing economies in the world since the Second World War. In fact, the annual growth rate of real GDP of Korea was around 8 per cent from 1961 to 2000 excepting the years 1980 and 1997 (Shin and Chang, 2003). This is shown in Figure VII-1.

Figure VII-1 Forty years' economic growth in Korea (unit: %)



Source: Shin and Chang, 2003, p. 2

This success story of Korea has been interpreted mainly by two different views: one is from the neoclassical economics; and the other is from alternative development theories (Chang, 2006). The former view regards the institutional changes forward free-market and free-trade systems as the main factors contributing to the economic success of Korea, while the latter emphasises the role of state and 'substituting institutions' on the process of development (Chang, 2006), as I discuss earlier in the literature review chapter (p. 26).

Because the focal point of the thesis is not to examine the disputes between the two views, I shall not deal with their main arguments in the thesis. However, I shall follow the latter view, the developmental state view, when I examine the Korean political economy in this chapter because it is more appropriate for the literature review and conceptual framework of the thesis, as described earlier.

2.2 Industrialisation of Korea: 1960s-1980s

2.2.1 Institutions for Industrial Policy

According to Gerschenkron (1962), industrialisation of backward countries was accompanied with establishing its own unique institutional instruments as 'substitutes for the lack of the supposed 'prerequisites' of development' (Shin and Chang, 2003, p. 10). He points out that 'investment banks' and 'the state' played the role of substitute institutions in the German and Russian industrialisation processes in the nineteenth century, respectively (Gerschenkron, 1962). From this perspective, three main features of the institutional setting of Korea can be identified in the process of its industrialisation. Firstly, the state had controlled the domestic and cross-border financial flow directly and strictly. In fact, the Park Chung Hee regime had hardly come to power before it nationalised all the banks in Korea in the early 1960s. Also, the Korean state had kept direct control over the banking system until the liberalisation of financial systems in the 1990s. Moreover, the Korean state maintained tight foreign exchange controls during this period (Amsden, 1989; Chang, 2006). Thus, the state was capable of enforcing industrial policy effectively, utilising financial tools such as policy loans or guaranteed foreign debts. Secondly, the Park regime set up the Economic Planning Board (EPB) as the super-ministry which was in charge of planning and budgeting. In order to eliminate conflict between planning and industrial ministries (which normally focus on long-term investments) and the finance ministry (which normally focuses on short-term stability), economic policy-making power was consolidated within the EPB. Therefore, due to the role of the EPB as control tower, the implementation of industrial policy was more effective than other industrialisation processes (Chang, 2006). Thus, the establishment of the EPB can be interpreted as an 'institutional innovation' (Chang, 2006) or institutional advantage for the industrialisation process of Korea. Thirdly, the Five Year Plan (FYP) was introduced by the Park regime for the first time in 1962. This was repeated six times over thirty years until the abolition in 1993. The FYPs geared various government policies toward the progression of 'independent economy' (*Jarip Gyongje*) as an 'overarching policy coordination framework', even though there were some revisions during the plan period (Chang, 2006). For instance, priority sectors which were designated by the FYPs extended and changed from cement, fertiliser, and oil refining industries in the first FYP (1962-66) to machinery, electronics, automobile, chemical, shipbuilding industries in the fifth and sixth FYPs (1982-91) (Chang, 2006). As a result, the FYPs enabled the Korean economy to grow fast by concentrating its resources on more promising sectors.

The industrialisation of Korea had been attributed mainly to these institutional implementations: the state's financial control, the existence of the EPB as a control tower of industrial policy, and long term planning of the FYP. The typical pattern of development in Korea is as follows: firstly, the state, mainly the EPB, selecting promising industries as priority sectors in the FYP; secondly, the state encouraging local companies, mainly large business groups such as *chaebols*, to enter into priority sectors and catch up with the leading foreign companies, providing them with a range of supports such as policy loans, guaranteed foreign debts, preferential tax treatments, and import protection and entry restrictions; lastly, *chaebols* achieving economies of scale in their manufacturing, and growing fast mainly through exporting their products to the global market (Chang, 2006). This kind of state intervention process is described as 'setting relative prices deliberately wrong' by Amsden (1989).

However, this explanation is not sufficient to explain the success of industrialisation in Korea. One of the weak points of this explanation is associated with rent-seeking theories (see Chang, 2006, p.87). For example, state intervention creates rents, and the state-created rents can lead to social waste such as rent-seeking behaviours like lobbying and corruption. In fact, there were a number of corruptions and lobbying activities in the industrialisation process of Korea. Therefore, what is the difference between the Korean experience and those of other countries such as Latin American countries (Chang, 2006), even though they seem to be similar in terms of state intervention in their development processes?

Amsden's (1989) answer to this question is that it was 'the discipline [Korean] state exercises over private firms' (p. 14). She explains in detail the process of discipline in

Korea as follows:

> Discipline may be thought of as comprising two interrelated dimensions: (a) penalizing poor performers; and (b) rewarding only good ones. Evidence of the former has taken two guises in Korea. First, in industries weakened at various times by over-expansion (some heavy industries, construction, shipping), firms have been subject to rationalization, … Second, discipline has taken the form of refusal on the part of the government to bail-out relatively large scale, badly managed, bankrupt firms in otherwise healthy industries (Amsden, 1989, p.15).

On the other hand, the discipline had been accompanied by the rise of big business groups, *chaebols*. Due to the performance-based incentive system, *chaebols* strengthened their economic power along with their economic performance (Amsden, 1989). For example, if they accomplish good performance of exports or new product introduction, they are rewarded with further licences to expand. Otherwise, however, they are punished by the state as described above. Sometimes, if the business is badly operated, the ownership is transferred to another *chaebol*. (Chang, 2006) Therefore, 'the *chaebols* had a powerful incentive to remain efficient, especially when the loss of state support can mean a sharp downturn in business in a few years' time, given the state control of credit and the high leverage of Korean firms' (Chang, 2006, p. 94). The role of *chaebols* in the industrialisation process will be described in detail in the next section.

2.2.2 Industrial Upgrading and Innovation

The industrialisation process of Korea can be interpreted as the process of industrial upgrading. In fact, the industrialisation began with light and labour-intensive industries such as the textile industry, mainly due to comparative advantages like low wages in the 1960s. As time went by, upgrading of industrial structure was proceeded mainly by the state intervention as I describe above[93]. As a result, six capital-intensive and high-tech

[93] According to the FYPs, priority sectors evolved as follows: 'The practice of giving priority to certain industries identified as important originated in the very early years of Korean development, with the designation of cement, fertiliser, and oil refining in the 1st FYP (1962-66) as 'basic' industries. In the 2nd FYP (1967-71), chemical, steel, and machinery were designated as 'priority' sectors. And during the 3rd and 4th FYP periods (1972-81), especially through the HCI [heavy and chemical industries] programme (announced in 1973), non-ferrous metals,

industries, petroleum refining, petrochemicals, iron and steel, electrical and electronics, automobile, and shipbuilding, became the leading industries in the Korean economy in the late 1980s.

Compared with the industrialisation in England, Germany and the US in the eighteenth and nineteenth centuries, industrialisation in the late twentieth century (including Korea's industrialisation) can be termed as 'late industrialisation' (Amsden, 1989). Whereas the former industrialisation occurred on the basis of invention and innovation, the late industrialisation occurred on the basis of learning (Amsden, 1989). Thus, Amsden (1989) emphasises learning as 'the new mode of industrialisation' that functioned as the main way to transfer technology.

However, if we define the concept of innovation broadly, as I discuss in the chapter of literature review, learning processes are not separable from the innovation process. Rather, (interactive) learning is argued to be essential to innovation (Lundvall, 1992). Whether the concept of innovation is defined broadly or not, Korea's industrialisation started with learning, went beyond imitation, and finally reached innovation (Kim, 1993; Kim, 1997a). The best examples are Samsung's technological learning in the semiconductor sector and Hyundai Motor's organisational learning in the automobile sector (Kim, 1997b; Kim 1998).

Although, the process of industrialisation was led mainly by the state, as I describe in the previous section, it should be noted that the *chaebols* were the protagonists of industrial upgrading and innovation in Korea. The *chaebols* became main players in the industrialisation under the heavy and chemical industrialisation programme in the 1970s, even though some of them began business in the early 1950s (Shin and Chang, 2003). They grew much faster than the overall economy. For example, the average annual growth rate of the top five groups was 31.6 between 1973 and 1977, whereas that of the Korean economy was 9.9 (Shin and Chang, 2003, p. 29). Under the state-led industrial policy, 'the state-banks-*chaebols* nexus thus became the central feature of the Korean economic system' (Shin and Chang, 2003, p. 13).

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shipbuilding, and electronics were added to the list of 'priority' sectors. The practice continued in the 5th and 6th FYP periods (1982-91), during which machinery, electronics, automobile, chemical, shipbuilding, and various high-tech industries (semiconductor, new materials, biotechnology) were designated 'priority' sectors' (Chang, 2006, p. 81).

Furthermore, *chaebols* had greater powers to exploit the economies of scale and scope from their diversification (Shin and Chang, 2003). Firstly, 'the structure of business group works as a mini-capital market for member firms' (Shin and Chang, 2003, p. 27). Member firms could mobilise financial resources through direct subsidy, corporate lending, loan guarantees, and so on. Secondly, they could increase the amount of capital through utilising leverage based on interlocked shareholdings (Shin and Chang, 2003). Mutual shareholding and circular shareholding were the easiest ways to increase their capital without actually putting in real money. Thirdly, the 'central office effect' could save their entrepreneurial resources (Shin and Chang, 2003). Technologies, engineering skills, marketing capabilities of the group could be shared to member firms.

Two examples of ways to utilise these advantages of business groups were the Hyundai Heavy Industries (HHI) and Samsung Electronics (SE). Firstly, HHI, which is one of the largest shipbuilders in the world, was set up by the Hyundai Group in 1971 in order to enter into the shipbuilding sector. Armsden (1989) describes its entry as follows:

> The top-ranking Korean manager of HHI was formerly a high level manager of the Hyundai Construction Company (HC), and when HHI ran into problems keeping to schedule, engineers from HC were mobilised. In addition, Hyundai Construction provided HHI with many of its front-line supervisors, managed the construction of the Mipo dockyard, and helped supervise feasibility studies. Hyundai Motors dispatched engineers to help in the struggle to reduce throughout time and also provided technical assistance in assembly line and training techniques. Hyundai Cement sent people to work in production control. All in all, as HHI managers pointed out, 'a lot of people joined'. The possibility of mobilizing such personnel enabled HHI to act quickly and to avoid delays of recruiting fresh talent in the market (Amsden, 1989, pp. 286-287).

Secondly, Samsung Electronics (SE), which is one of the leading firms in the semiconductor sector, was set up by the Samsung Group in 1974 as follows (Shin and Chang, 2003).

> Samsung's foray into semiconductors would not have been possible without the intra-group resource mobilisation. The group started the semiconductor business by acquiring a venture firm, Korea Semiconductor Inc. (KSI) in 1974, whose name was changed to

> Samsung Semiconductor Co. (SSC) in 1978, and later to Samsung Semiconductor and Telecommunication Company (SST) in 1982. This semiconductor firm was 'notorious within the Samsung Group as a symbol of low productivity' (Choi 1994: 87). … But the company maintained an over 50 per cent investment-to-sales ratio all through the 1980s, which was sustained by the group's strategic concern and financial support from member firms. SEC [Samsung Electronics Co.] on its own was much smaller than its key competitors such as Toshiba or Hitachi, but the Samsung Group was comparable to them in size. SEC compensated for its relative lack of resources as compared to Japanese forerunners by group-level resource mobilisation and more narrowly focusing its catching-up effort on DRAM manufacturing (Shin 1996: Ch. 8) (Shin and Chang, 2003, pp. 30-31).

In short, state-banks-*chaebol* nexus was the most distinctive feature of the industrialisation of Korea during this period (Shin and Chang, 2003).

2.3 Liberalisation and the Crisis: 1990s

2.3.1 Rising Neo-liberalism and Financial Liberalisation

Under the influence of the global trends of neo-liberalism such as Reaganomics and Thatcherism, neoliberal ideology began to prevail in Korea from the late 1980s[94] (Chang, 2006). Furthermore, the power of *chaebols* became greater and greater in Korea, and they attempted to escape from government intervention (Chang, 2006). From this background, the Kim Young Sam regime took over power in 1993 under the slogans of globalisation and small government, which meant the Anglo-American neo-liberal economic model and the minimal state.

Firstly, the regime scrapped the key developmental instruments under the slogan of small government. Although the traditional industrial policy started to wane from the

[94] Pirie (2008) explains that 'the disintegration of the Korean developmental state' (p. 8) began from the early 1980s despite its processes were uneven, slow and piecemeal. And he criticises that the state-institutionalist analysis focuses on domestic policies rather than supranational political and economic changes. Moreover, he argues that 'the neo-liberal reform was rational from the perspective of Korean capitalism' (p. 9), and this reform inevitably resulted in the 1997 crisis (Pirie, 2008).

late 1980s, the decline of developmental state culminated in this regime. 'On its assumption of power in 1993, the Kim Young Sam government abolished the practice of five-year planning, which had provided an overarching policy coordination framework since its introduction in 1962' (Chang, 2006, p. 214). Moreover, 'in the name of government administrative 'rationalisation' [small government], the planning ministry, Economic Planning Board (EPB), was merged with the Ministry of Finance (MOF), forming the super-ministry, Ministry of Finance and Economy (MOFE), which symbolised the demise of (indicative) 'planning' in Korea' (Chang, 2006, p. 214). This meant that two main institutional instruments which had played a decisive role in economic development were removed from the Korean political economy.

Secondly, more important institutional change occurred in the Korean financial system under this regime[95]. Although a series of financial liberalisations began to happen during the 1980s, the liberalisation process did not accelerate greatly until the appearance of the Kim Young Sam regime. This regime announced the five-year financial liberalisation plan in 1993 which aimed at the significant and unprecedented change in the financial system as follows: 'interest rate deregulation, abolition of 'policy loans', granting of more managerial autonomy to the banks, reduction of entry barriers to financial activities and, most importantly, capital account liberalisation' (Chang, 2006, p. 208).

In addition to the abolition of the FYP and EPB, this financial liberalisation dismantled industrial policy through removing policy loans which had been one of the most powerful tools of the government in the industrialisation process. Under this deregulation and liberalisation, the foreign exchange crisis was about to hit the Korean economy.

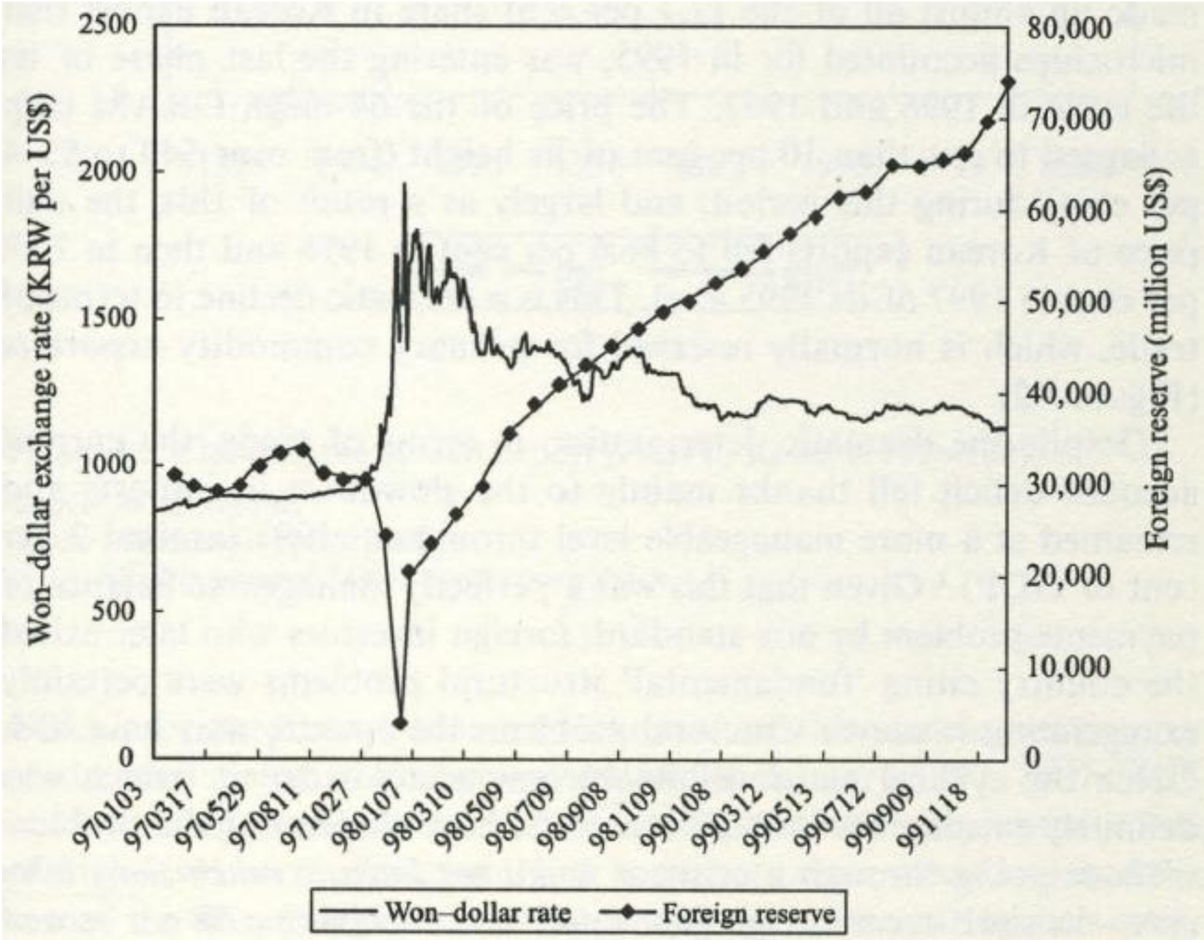
2.3.2 The 1997 Crisis and the Restructuring of the Economic System

The Foreign Exchange Crisis of Korea happened suddenly without any expectation in December 1997, even though the Asian financial markets were unstable due to the Thai

[95] At the same time, this financial liberalisation proceeded under pressure from the US government (Chang, 2006).

and the Indonesian financial crises (Chung, 2003). The Korean currency (*Won*) fell to around one-third of its value before the onset of the crisis as shown in Figure VII-2. Finally, the Korean government announced that it would call in the IMF on 3rd December 1997 (Shin and Chang, 2003).

Figure VII-2 The currency crisis in Korea in 1997-98



Source: Shin and Chang, 2003, p. 35

There are two different views about the cause of the crisis: one argues that this crisis resulted from long-term structural factors of the Korean economic system which was fundamentally inefficient mainly due to moral hazard and corruptions; the other argues that the crisis was caused by the short-term macroeconomic mismanagement under the financial liberalisation (Shin and Chang, 2003). The latter view seems more reasonable than the former, because it explains the evolution of the crisis and the rapid recovery of the Korean economy. However, the former view sheds light on the restructuring programmes after the crisis (Chung, 2003).

When it comes to the evolution of the crisis, it happened directly due to the lack of foreign reserve as shown in Figure VII-2 and the rejection of the foreign financial institutions to roll over the short-term[96] loans of the Korean financial ones since late October in 1997 (Chung, 2003). Although the ratio of foreign debt/GNP was at a sustainable level, the critical point was the maturity structure of the foreign debt (Shin and Chang, 2003). In fact, the share of short-term one in total foreign debt rose from around 30 per cent in the 1980s to 58 per cent at the end of 1996 (Shin and Chang, 2003). This increase mainly resulted from the 'inexperienced merchant banks (officially called 'merchant banking corporations') newly licensed by the Kim government in the name of financial liberalisation' (Chang, 2006, p. 212). Furthermore, the proper regulation and monitoring systems on the merchant banks were not established under the trend of deregulation, as pointed out by Chang (2006).

> Moreover, supervision of the merchant banks, unlike that of the deposit banks, was virtually non-existent, to the extent that the Kim government was apparently not even aware of the huge mismatch in the maturity structures between their borrowing (64% of their $20 billion total foreign borrowings were short-term) and lendings (85% of them long-term) that existed on the eve of the crisis (Chang, 2006, p. 213).

As a consequence, it can be concluded that the crisis was due mainly to financial liberalisation's lack of consideration to proper regulation and supervising systems under the deregulation and globalisation slogan (Shin and Chang, 2003; Chung, 2003).

However, after the crisis the government restructuring programmes focused on not only the financial systems but also corporate reform, especially the reform of the *chaebol* (Shin and Chang, 2003). Firstly, the Korean government enforced a range of measures to restructure *chaebols* in order to lower financial risks in the corporate sector. Major measures were the reduction of the debt-equity ratio, fair trading regulations mainly on internal transactions within the business group, the introduction of consolidated financial statements, and the liberalisation of M&A markets (Shin and Chang, 2003). In fact, the debt-equity ratio of thirty largest *chaebols* reduced dramatically from 513 per

[96] A short-term loan is defined as a loan with less than a year's maturity (Shin and Chang, 2003).

cent in 1997 to 171 per cent in 2000 (Shin and Chang, 2003). Most of these measures were implemented by the Fair Trade Commission (FTC) under the strengthening of its regulations on *chaebols*.

Secondly, the restructuring of the financial sectors was undertaken by the Financial Supervisory Commission (FSC), which was established as a comprehensive regulation scheme in April 1998. At first, 572 ailing financial institutions were shut down and several major commercial banks were nationalised by the bail-outs. In addition, financial supervision standards were significantly strengthened. For example, the minimum capital adequacy standard[97] of BIS (the Bank for International Settlements) was strictly applied to the bank regulations (Shin and Chang, 2003).

Thirdly, the Korean government attempted to find alternative engines of growth in FDI and venture businesses. However, unlike the anticipated benefits, the efforts of attracting foreign investment largely resulted in asset sales at bargain prices not green field investments. Furthermore, the venture boom, which occurred in 1999 mainly due to the efforts of nurturing venture businesses, ended with the bursting of the huge speculative bubble in the KOSDAQ (the Korean version of NASDAQ) in 2000 (Shin and Chang, 2003).

As a consequence, the institutional reforms after the crisis have removed the long-term investment dynamics from the economy by dismantling the ability of Korean companies to access large investment funds. Because financial institutions became extremely conservative under the restructuring of the financial system, indirect financing of the corporate sector shrank. On the other hand, direct financing was not sufficient to compensate for it. Furthermore, the corporate sector, especially *chaebols*, lost their powerful tools of mobilising resources such as internal transactions and mobilisation within their business groups. Therefore, these institutional changes, which can be interpreted as the introduction of the Anglo-American economic system, weakened the ability of the Korean economy to grow.

[97] The minimum capital required should remain at 8% of risk weighted assets.

2.4 Contemporary Political Economy: *Chaebol*-dominant Structure under the Anglo-American System

According to Gerschenkron's (1962) fundamental insights, a backward economy can catch up with advanced countries when it devises substituting institutional instruments in order to compensate for its relative lack of the prerequisites such as capital, technology, and so on (Shin and Chang, 2003).

As a matter of fact, under the process of the industrialisation in Korea between the 1960s and 1980s, the state, banks, and *chaebols* cooperated with each other and shared the risk of large-scale investment projects through forming the 'state-banks-*chaebols* nexus'. This can be interpreted as the substituting institutions. However, the institutional changes which took place after the 1997 crisis have restructured the Korean economic system geared to the Anglo-American one which is focused not on long-term development strategy but on the stability of the financial sector (Shin and Chang, 2003).

Through these institutional changes, the ability of risk taking of the Korean economy has been dampened because the state-banks-*chaebols* nexus was dismantled and there is non-existence of risk taking agents such as the banks and *chaebols* of the industrialisation period (Shin and Chang, 2003).

3. EVOLUTION OF THE PV INDUSTRY IN KOREA

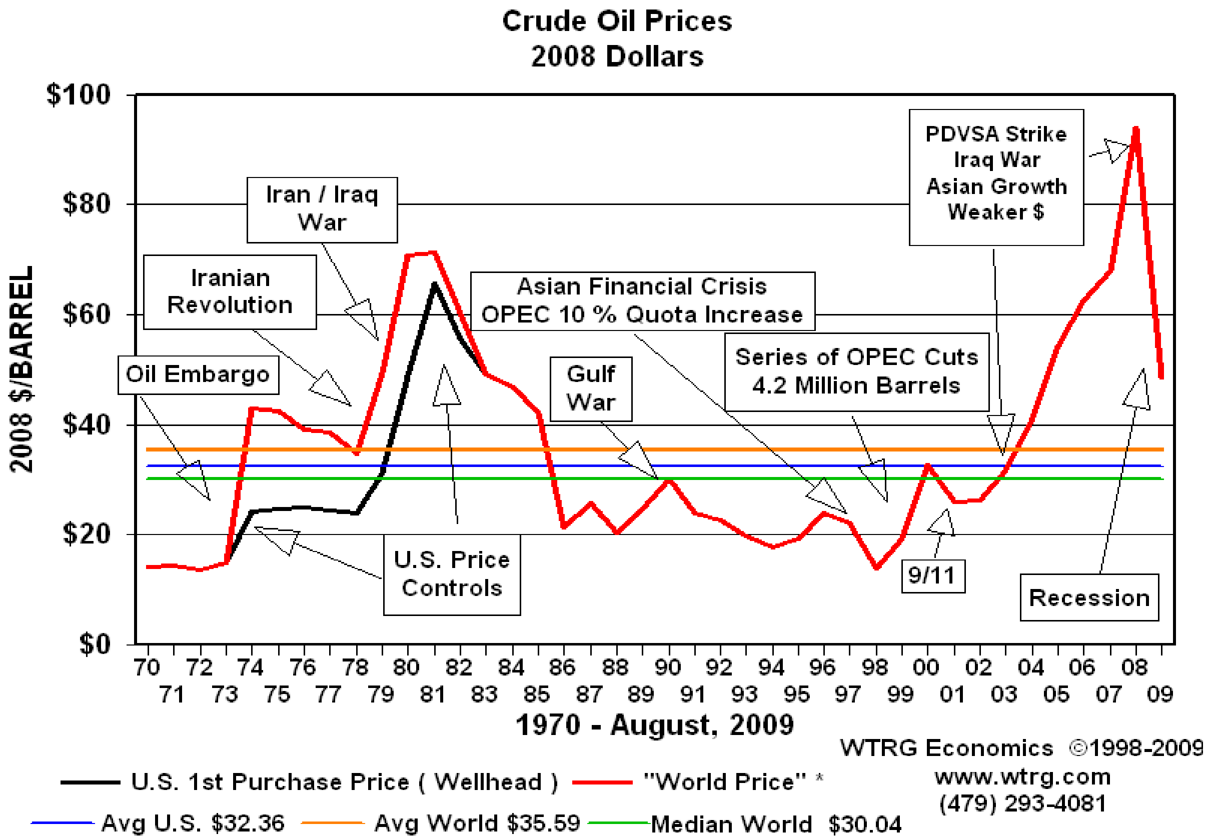
3.1 Importation of Knowledge: 1970s to 1980s

While the creation of basic knowledge on PV and the invention of new PV products were the starting point of the PV industry in advanced countries such as Germany, as I described in chapter V, the importation of this knowledge from foreign countries was interpreted as a starting point of the PV industry in backward countries such as Korea. Thus, I shall begin with the importation of foreign knowledge from foreign countries in order to deal with the evolution of the PV industry in Korea.

3.1.1 Oil Shocks and Institutional Changes

The first oil shock of 1973 and the second oil shock of 1978 had a huge impact on the Korean economy as well as on the world economy because the domestic energy supply was heavily dependent on imported oil. Moreover, because the Korean government implemented ‘heavy and chemical industrialisation’ as a economic development strategy in the 1970s, petroleum consumption accounted for 53.8 % and 63.3% of the primary energy consumption in 1973 and 1978, respectively (MOER, 1988). In addition, the surge in crude oil prices after the two oil shocks, as you can see Figure VII-3, caused inflation in the domestic economy and worsened the trade deficit. Thus, the government realized that a stable supply of energy and less dependency on oil were essential to economic growth.

Figure VII-3 Crude Oil Prices from 1970 to 2009 (unit: USD)



Source: WTRG Economics (http://www.wtrg.com/prices.htm)

For this reason, the Korean government established 'the Ministry of Energy and Resources (MOER)' in January 1978 in order to make energy policy and diplomacy independently (MOER, 1990). In addition, 'the Korea Energy and Resources Research Institute (the current Korea Institute of Energy Research: KIER)' and 'the Korea Energy Management Corporation (KEMC)' were founded in 1981 and 1980, respectively (MOER, 1990). These three public organisations played a major role in the development of PV technology and the deployment PV markets. Thus, the establishment of these organisations can be regarded as 'institutional change' which is one of the four features[98] of a formative period of the transformation of an energy system (Jacobsson and Bergek, 2004).

Another substantial 'institutional change' was the legislation of the 'Alternative Energy Development Promotion Act (AEDPA)' in December 1987 (MOER, 1990). This act,

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[98] Jacobsson and Bergek (2004) argue four features of formative period as follows: market formation, the entry of firms and other organisations, institutional change and the formation of technology-specific advocacy coalitions.

which mainly stipulated how to develop alternative energy technology, was the starting point for explicit PV support policy in Korea as well as other renewable energy sources.

In order to implement the Alternative Energy Development Promotion Act (AEDPA), the government formulated a fourteen-year master plan in June 1988. In this plan, the government set the target of 3% of alternative energy contribution to total energy supply by 2001 (MOER, 1990). Considering the contribution of alternative energy, mostly hydropower energy[99] at that time, was 1.2% in 1989, the target of 3% was very ambitious one (MOER, 1990). Furthermore, the government designated PV and fuel cells as priority sectors through the National Project. This project was provided with substantial R&D funds and implemented by the consortium of firms, universities, and government research institutes (MOER, 1990).

Due to these institutional changes, the research into PV technology began to increase in universities and government research institutes in Korea, as I will describe below.

3.1.2 Importation of Foreign Knowledge

In view of research into PV science and technology, much research had been carried out in the US, Japan, and the USSR by the 1980s, as shown in Table VII-1.

Table VII-1 Number of publications of literature about ‘photovoltaic’, 1900-1989

	US	Japan	USSR	France	India	Canada	Italy	Germany	China	Korea
number	389	95	67	56	53	39	29	27	7	5

Source: Web of Science (Searching the literature by topic with term of ‘photovoltaic’)

Looking at the number of research publications in Korea year by year, there was one in 1986 and two in 1987 and 1988, respectively. This shows that major research into PV technology started after the institutional changes in the 1980s in Korea. According to the ‘Alternative Energy Technology Census’ (1988) of Korea, 94 researches into PV were carried out between 1964 and 1987. Thus amount of research into PV technology

[99] In terms of the AEDPA of Korea, only small hydro is included in alternative energy by definition, however, generally large hydro is also included in alternative energy, for example in IEA statistics.

increased greatly after the oil shocks and the institutional changes (KEEI, 1988).

On the other hand, compared with advanced countries, it is not surprising that Korea's scientific knowledge of PV lagged far behind at the time. While research in advanced countries mostly focused on the creation of new knowledge and the invention of new products, the level of research in Korea was based largely on knowledge introduced by foreign scientists. According to the 'Alternative Energy Technology Census' (1988) of Korea, in terms of the quality of research, 67% of research results were evaluated as 'under the level of developed countries' or as 'introduction of foreign knowledge' (KEEI, 1988). However, the importation of foreign knowledge was an essential process in establishing a new industry in backward countries because this knowledge was created by foreign scientists.

Moreover, research areas were biased towards chemical mixture solar cells rather than crystalline silicon solar cells because of lower cost of experimental instruments and more foreign references (KIER, 1992). In the view of funding, the average scale of one PV research project was 28.3 million Korean *Won* (KW) (approx. 28,300 USD), making it smaller scale than that of coal slurry research which was 57.6 million KW (approx. 57,600 USD) (KEEI, 1988). This is likely to be due to the simplicity of PV research at the laboratory level. For example, typical PV research was the fabrication of small-sized solar cells, for example a solar cell sized 1cm x 1cm[100].

It should be noted that only universities and government research institutes took part in this research. No firms participated in research into PV technology until the 'National Project' was launched in 1989 (KIER, 1992). This may reflect the fact that the level of technological capability of firms was not sufficient to carry out 'proprietary activities' such as applied R&D and developing and commercializing products (Van de Ven and Garud, 2000, p.493).

3.1.3 Domestic Niche Markets

[100] Currently, a normal solar cell size is a 16cm x 16cm.

The first PV systems were installed on unattended lighthouses by the Korea Maritime and Port Administration (KMPA) in 1972 in Korea. KMPA extended PV systems to manned lighthouses in the 1980s because it had been established that PV systems were more reliable and economical than diesel systems (KERRI, 1982). In addition, Korea Telecommunication used PV systems for the generators of remote stations on islands. Furthermore, Korea Electric Power Corporation began to build PV systems for the electrification of remote islands from 1987 (KIER, 1992).

Almost all of the PV systems were small scale systems around 10 kWp in this period, thus the total annual capacity installed was under 200 kWp till 1989, as shown in Figure VII-4 and Table VII-2.

Figure VII-4 Annual PV installed in Korea, 1978-1989 (unit: kWp)

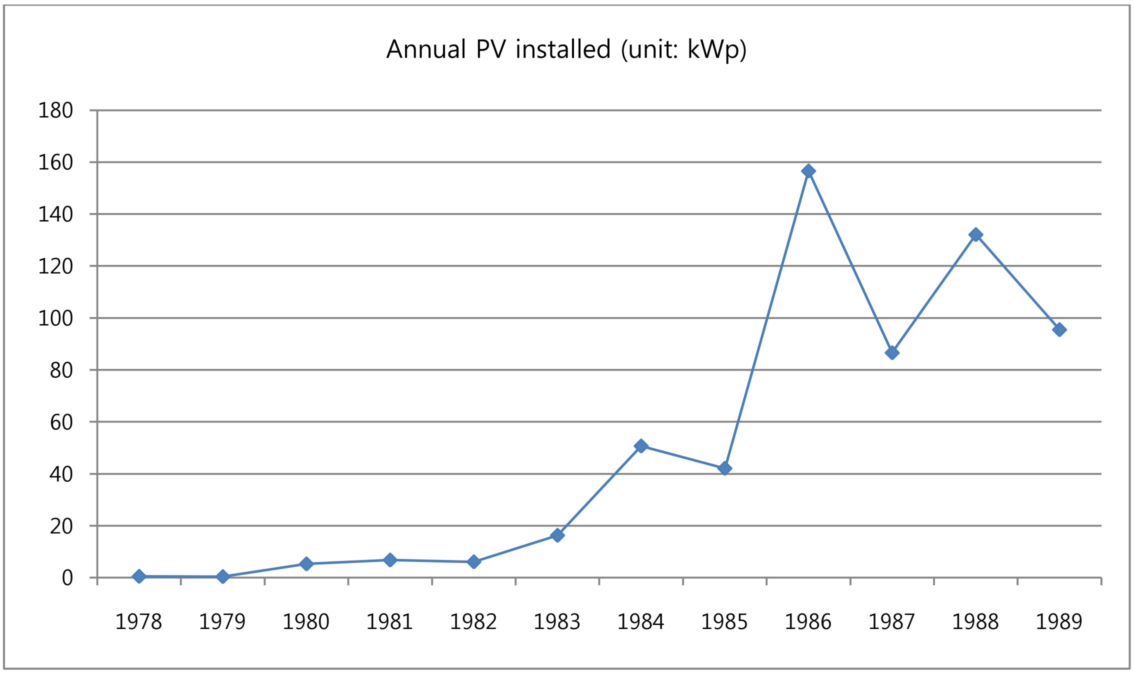


Table VII-2 Annual PV installed in Korea, 1978-1989 (unit: kWp)

	78	79	80	81	82	83	84	85	86	87	88	89
kWp	0.5	0.4	5.3	6.8	6.1	16.3	50.7	42.1	156.6	86.6	132.1	95.5

Source: Korea Energy Management Corporation, Alternative Energy Statistics

The domestic market of this period has two characteristics: one is its limited size; the other is specialisation of use. Firstly, the size of the domestic market was smaller than the minimum efficient scale of mass production at that time. A manager of a PV firm says that minimum efficient scale in manufacturing solar cells was at least 500kWp at that time (Bae, 2009). Thus, domestic demand was not sufficient for Korean firms to pay attention to the PV sector unless they intended to export. Therefore, one of the reasons why all solar modules were imported lay in the small domestic market size and the absence of export markets as well as a lack of technological capability in this period.

Secondly, most buyers of PV systems were public organisations, not private ones. This meant that almost all the markets were public procurement markets, where the size of the market relied on government budget. Thus, the market size could fluctuate and did, as you can see in Figure VII-4. The fluctuation of the market meant uncertainty for firms and this was likely to hinder firms' investment, because firms tend to avoid risk and uncertainty when considering investing.

In short, the small size and uncertainty of the domestic market was one of the main reasons for Korean firms not to be interested in the PV industry in this period.

3.2 Attempts of PV Manufacturing: 1990s

3.2.1 The National Project: Big Supply-push (1989 – 1992)

3.2.1.1 Consortium of Firms, Universities and Research Institutes

The Korean government formulated the first Alternative Energy Technology Development Master Plan in 1988, as I mentioned above. The term of the Master Plan was between 1988 and 2001, and it was divided into three phases within the plan. In the first phase, between 1988 and 1991, PV and fuel cell sectors were selected as the National Project, which was a large-scale R&D project carried out by the consortium of firms, research institutes and universities for the first time in Korea. The participation of firms implied that the level of this project was beyond the existing laboratory one. Thus, the goal of the National Project was initiating commercialization and diffusing technology (MOER, 1992). This can be described as the first big 'supply-push policy' (Mowery and Rosenberg, 1979) for innovation in the PV sector in Korea.

In detail, the targets of the PV National Project were as follows: the development of a 100kWp scale PV system; the achievement of reaching over 15% conversion efficiency of mono-crystalline silicon cells and over 12% conversion efficiency of solar modules; and the reduction in price of solar modules to 3,500KW/Wp (approx. 3.5 USD/Wp) (KIER, 1992). In the context of energy policy, acquiring PV production technology meant that energy sources were able to become domestic and diverse so that dependency on imported oil could be reduced. In other words, the PV National Project sought to link two goals: one is the development of PV technology; the other is the deployment of PV electricity. Policy makers seemed to believe that building the local production capacity of PV systems could lead to increased PV installation by using PV systems produced locally. This can be interpreted as an ‘unintended import substitution policy’, not an export-led policy which was dominant in other sectors such as the electronics sector in Korea. This perspective can be found in many government documents and government research institute reports (KIER, 1991; KIER, 1992; MOER, 1992).

Participants in the PV National Project and the titles of R&D programs are shown in Table VII-3. There were three types of participants: firms, institutes and universities. In Korea, the National Project was the first R&D into PV in which firms took part. After firms got involved in R&D, the focus of R&D moved from basic science and knowledge to applied technology and problem solving. One of the participants in the National Project said, “The National Project was totally different from the previous PV R&D. The latter was a kind of small-scale experiment in the university laboratory, while the former was a big project through collaboration between firms, institutions, and universities” (Yoon, 2009).

Table VII-3 Participants and program titles of the PV national project

Participant	type	Title of program
Siltron	firm	Fabrication Technology Development of Low Cost, High Efficiency Crystalline Si Solar Cells
Goldstar Central Institute	institute	The Development of Large Area Amorphous Silicon Solar Cell
KIST	institute	Fabrication of High Efficiency Amorphous Silicon Solar Cells
Kyunghee	university	Fabrication Technology of Amorphous Silicon Tandem Solar Cells
Seoul National	university	Fabrication and Investigation of Degradation Phenomena of

		Amorphous Silicon Solar Cells by Photo CVD
KIST	institute	A Study on Enhancing the Efficiency of Amorphous Si/Metal Substrate Type Solar Cells by three-chamber Photo-CVD Method
Goldstar	firm	Development of DC/AC Converters for the Power Generating System using the Silicon Solar Cell and the Phosphoric Acid Fuel Cell
Yukong	firm	Development of Zinc/Bromine Battery for Photovoltaic Energy Storage
Sebang Battery	firm	Improvement of Lead-Acid Batteries for Photovoltaic Power Generation System
Hankook Glass	firm	Development of Transparent Conducting Films for Substrates of Amorphous Solar Cell
Korea	university	A Study on the Standardization of Solar Array Support
Korea Eletrotechnolgy Research Institute	institute	Study on the Optimization and Economical Diffusion Scheme of Photovoltaic Power Generation System
Korea Research Institute of Standards and Science (KRISS)	institute	Testing and Evaluation of Lead-Acid Batteries Used in Solar Photovoltaic Power System
KRISS	institute	Development of Sealed Lead-Acid Battery for Solar Photovoltaic Power System
KIER	institute	A Study on the Performance Measurement and Evaluation Procedures for Photovoltaic Devices
KIER	institute	A Study on the Standardization of Photovoltaic System for Remote Islands
KIER	institute	Studies on Performance Improvement of SnO_2 Transparent Conducting Films by Pyrosol Deposition Method for use in a-Si Solar Cells
KIER	institute	Development of High Efficiency DC-AC Inverters for PV System
Korea Research Institute of Chemical Technology	institute	Production of Polycrystalline Silicon Wafer for Solar Cell by the Casting Method

Source: Analysis Report on Alternative Energy R&D Program (MOER, 1992)

In view of the scale of budget, the National Project was also remarkable. During the three years, from 1989 to 1991, the R&D budget for photovoltaic was 6,031 million KW (approx. 6 million USD) let alone 5,880 million KW (approx. 5.9 million USD) of private funding. In addition, the government supported 2,766 million KW (approx. 2.8 million USD) for purchasing R&D instruments and equipment. Thus, the total amount of finance was 14,677 million KW (approx. 14.7 million USD). However, considering that the budget for PV R&D in Germany, Japan and the US was respectively, 61, 53, and 34 million USD in 1990, the budget for the National Project in Korea was not so extraordinary. However, the annual R&D budget for PV was about ten times higher than the total alternative energy budget, which was just around 500 million KW (approx.

0.5 million USD) in the 1980s (MOER, 1990). Therefore, it is not difficult to assume that there must have been a big change in allocating the energy R&D budget in the late 1980s in Korea.

3.2.1.2 The First Solar Cell Production

In evaluating the achievement of the National Project, I will focus on Siltron's programme, because manufacturing of crystalline silicon solar cells is one of the most important prerequisites in establishing the domestic PV industry. In fact, Siltron accomplished 16.5% conversion efficiency of silicon solar cells and constructed a solar cell production line of 300kWp annual capacity by the end of 1992 through the participation in the National Project. However, the price of solar modules estimated at 6,937KW (approx. 7 USD) /Wp was about twice as high as 3,500 KW/Wp (the target of National Project) (MOER, 1992). Considering that the international price and efficiency of solar modules was around 4 USD/Wp and about 15% at that time (Song, 1994), Siltron's solar cells were therefore not competitive in the global market. However, according to the government report, Siltron's solar cells might compete with imported solar cells in the domestic market (MOER, 1992).

In short, Siltron's programme was technically successful in fabricating mono-crystalline silicon solar cells, whilst the program failed to produce silicon solar cells at a low enough cost to compete with foreign solar cell manufacturers in the global market.

However, looking at a typical sequence of a catching-up process and other industries' experiences in Korea, this goal of price seemed to be impossible to achieve within one R&D project. Acquiring basic technology capability to produce (imitation mode), investment to achieve a reduction in cost through economies of scale, upgrading technology capability through learning by doing, investment R&D to adapt, and improvement and development of one's own technology (innovation mode) were a basic formulation in establishing an industry in the industrialization of Korea (Kim and Dahlman, 1992). For example, Samsung's technological learning in semiconductors required a lot of trial and error in R&D and manufacturing, thus taking a long time (Kim, 1997b).

From this perspective, Siltron's programme was likely to have to start from scratch in building technological capability of the PV industry in Korea.

3.2.2 Revision of 'the Promotion Act': the First Demand-pull (1997)

3.2.2.1 Climate Change Issue and Local Background

In the 1990s, the climate change issue had growing influence on the international agenda. In June 1992, 'the United Nations Framework Convention on Climate Change (UNFCCC)' was signed as an international environmental treaty by about 150 nations in Rio de Janeiro. Furthermore, in December 1997, the 'Kyoto Protocol' was adopted as establishing legally binding obligations for developed countries. These international circumstances put major pressure on the Korean economy to transform current development into sustainable development (MOTIE, 1997a).

In addition, the Korean government restructured ministries, so MOER (Ministry of Energy and Resources) was merged into MOTIE (Ministry of Trade, Industry and Energy) in 1993. This implied that the industrial policy perspective might receive more weight than the energy policy perspective within alternative energy policy. Actually, the government adjusted the Alternative Energy Development Master Plan, expanding the period to 2006 (previously to 2001) and lowering the target from 3% to 2%. This was because the government judged the achievement of 3% by 2001 as impossible considering slow technology development and low oil prices in the 1990s (MOTIE, 1997a). Because of the modification of the target and period, the Plan became more realistic and attainable than previously.

On the other hand, the domestic alternative industries as well as the PV industry claimed that more government support was needed in order to create demand for alternative energies so that they were able to succeed in commercialization of alternative energy technology. Without government supports, alternative energy industries could not survive in the market, because most alternative energies were still more expensive than conventional energy (Lee, 1997; Song, 1998).

3.2.2.2 Revision of the Promotion Act

Under international influence and domestic pressure, the Alternative Energy Development Promotion Act was revised to become the Alternative Energy Development and *Deployment* Promotion Act in December 1997 (MOTIE, 1998). The main points of this revision, as you can infer from the title of the revised act, were not only to develop alternative energy technology but also how to deploy it (CTI, 1997). Major additions were as follows: the Alternative Energy Development Master Plan should include not only the development of alternative technology but also the deployment of alternative energy; the government could recommend public agencies to utilize alternative energy; and the government could implement alternative energy demonstration programmes, etc. (CTI, 1997).

This revision of the act was the first systemic demand-pull policy for alternative energy. However, the industrial policy perspective was not the first priority within this revision. The enforcement of the UNFCCC was the first reason to revise this act (CTI, 1997). As a consequence, setting a target and accomplishing the target became important in order to reduce CO_2 emission. This was one of the reasons why the government modified the alternative share target from 3% to 2% and extended the deadline from 2001 to 2006.

Following the first legislation of this act, more interactions between actors of governance, technology and market areas also took place. Some interest groups, such as solar thermal firms and renewable energy researchers were interested in this legislative process and expressed their opinions in support of the revision (KIER, 1997).

3.2.3 Difficulties of the PV Industry

3.2.3.1 Stagnation of the Domestic PV Market in the 1990s

Due to the National Project, a 100kWp photovoltaic generation system, which was made in Korea, was installed on Ho-island for the first time (KIER, 1992). In contrast to the efforts in PV technology development by the National Project, domestic PV demand shrank to a low of 50kWp in 1994, as you can see in Figure VII-5 and Table VII-4.

Figure VII-5 Annual PV installed in Korea, 1990-1999 (unit: kWp)

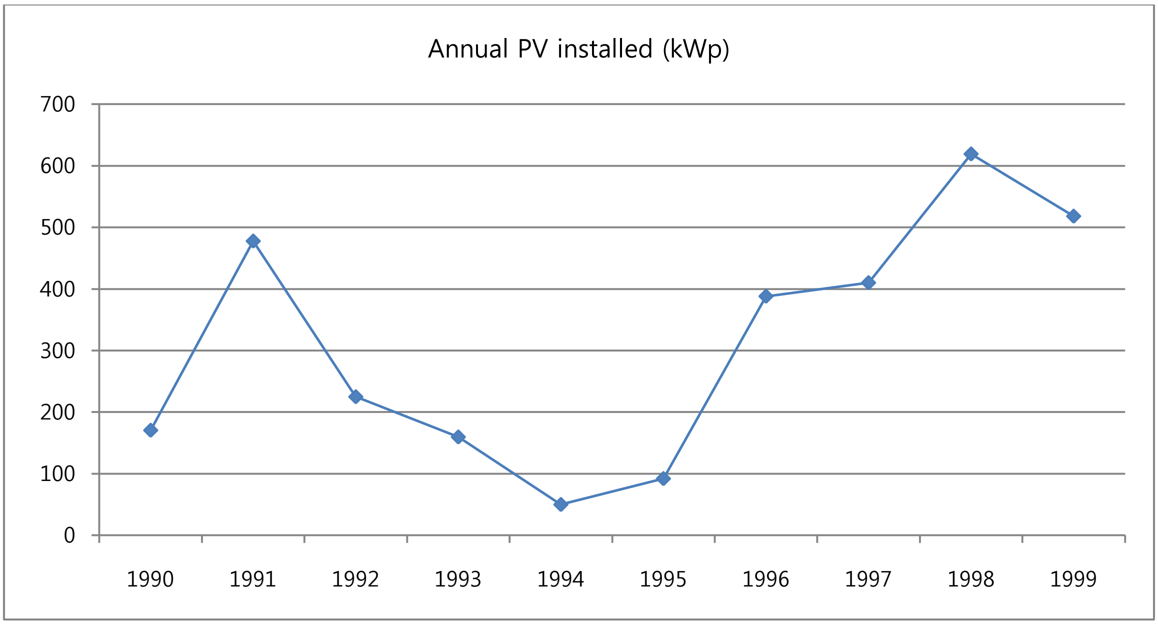


Table VII-4 Annual PV installed in Korea, 1990-1999 (unit: kWp)

	90	91	92	93	94	95	96	97	98	99
kWp	170.5	477.6	224.9	159.6	50	92	388	410	619	518

Source: Korea Energy Management Corporation, Alternative Energy Statistics

The main reasons why domestic PV markets contracted were likely to relate to the PV market structure. As in the 1970s and 1980s, the main domestic buyers in the 1990s were the Korea Maritime and Port Administration (a ministry), the Korea Telecommunication (a public corporation), and the Korea Electric Power Corporation (a public corporation). They used most solar PV power systems for lighthouses, remote telecommunication stations, and the electrification of remote islands. Therefore, domestic demand for solar systems relied heavily on the public budget for their own administrative objectives not put towards the goal of deploying alternative energy. Thus, the decrease in domestic demand was mainly due to the reduction of budget for them. Furthermore, the scales of most PV systems were very small because all the PV systems were of the stand-alone type. This also reduced the total demand for PV systems.

In addition, the crude oil price was around 20 USD/barrel in the 1990s (Figure VII-1 p. 168). Enthusiasm for the development of alternative energies had a tendency to be linked to oil prices. One of the Korean PV entrepreneurs comments that “the relationship between oil prices and the amount of R&D fund for renewables is positive. At the beginning of the National Project, firms which took part in the project were very passionate for R&D. But, as the oil price fell down, their passions were also getting weaker" (Park, 2010).

On the other hand, in the second half of the 1990s, the domestic PV demand increased steadily due to demand-pull policies such as the revision of the act. During the revision of the act, the government fully supported the construction of the first on-grid 30kWp photovoltaic systems at Changwon city hall in November 1997 through the demonstration programme (MOTIE, 1997b). After the revision, government allocated 33, 33.3, and 27.8 billion KW (approx. 33, 33.3, and 27.8 million USD) budgets for the preferential loan to alternative energy system installation or alternative energy firms in 1998, 1999, and 2000, respectively (MOTIE, 1998; MOTIE, 1999; MOCIE, 2000).

However, the domestic demand for PV systems was still so limited that it did not reach 1MWp by the end of 1999, as Figure VII-5 and Table VII-4 shows us. The amount of annual domestic demand was around 500kWp in the 1990s, far under 2 MWp of the domestic module annual production capacity. This meant that the first demand-pull policy was not sufficiently effective in expanding the demand for PV systems. Furthermore, domestic firms' seemed not to have entrepreneurship to export their product like typical export-led sectors. As a consequence, firms' entry, private investment, and technological innovation were stagnant as I will discuss below.

3.2.3.2 Shut Down of the First Production Facility

The National Project for development of PV systems can be regarded as a starting point for the Korean PV industry. It was the first project in Korea in which main actors of governance, technology, and market areas interacted and cooperated. In fact, Siltron (the first solar cell manufacturer in Korea) completed its solar cells production line at 300kWp of annual capacity in 1992 through the National Project and extended its capacity to 500kWp later. In addition, Goldstar Industrial System attained its mono-crystalline silicon solar module production line at 500kWp of annual capacity in late 1992. Moreover, Samsung Electronics achieved a solar module line at 500kWp of annual capacity in early 1994, and Hacksim Chemical built a solar module line at 500kWp of annual capacity in late 1994 (KIER, 1997).

However, commercialization of PV systems after the National Project was in retard. One of the main reasons for the PV industry's failure to progress seems to be weak domestic demand. Most renewable energy industries have a stage of 'valley of death' between demonstration and commercialization (Carbon Trust, 2006 cited in Watson, 2009, p.135). Thus, 'nursing markets' should be provided to renewable technology for market formation (Ericsson and Maitland, 1989 cited in Jacobsson and Bergek, 2004). That is to say, in order to create a successful renewable energy industry, not only technically but also commercially, policies need to be 'designed to provide effective linkages between the demand and supply sides' (Kim and Dahlman, 1992). To illustrate this point, public procurement policies played a major role in the formation of an initial market when the computer industry emerged in the early 1980s (Kim and *et al.*, 1987).

In line with this, the demand-pull policy was introduced by the revision of the Promotion Act in late 1997. However, the demand which was created by the policy was not large enough to lead to the growth of the PV industry.

Moreover, forerunner PV companies such as Sharp hindered potential future rivals from successfully entering into the PV market. For example, Japanese firms' strategic behaviour prevented Korean PV firms' from settling down successfully in the Korean PV market. They cut the price of PV modules to around half price in the Korean market (Lee, 2000). As a consequence, the total production of solar modules by Korean PV firms came to 452kWp in 1995, 352kWp in 1996, and 370kWp in 1997, whilst total annual production capacity reached 2MWp. Therefore, the ratio of their working production line was under 20% during these three years (Song, 1998).

According to the industrialisation experience in Korea, usual industrialisation sequences are as follows: firstly, building the first production capability by importing capital goods or reverse engineering etc; secondly, accumulating technological capability by substituting for import in the domestic market; thirdly, reducing costs by economies of scale and exporting to global markets; and lastly, upgrading technological capability by investment in R&D and developing products and services (Kim, 1993). Some producers skipped the second step in circumstances where the domestic market was small. With regard to the PV industry in the initiation period, early entrants, such as Siltron, Goldstar Industry System, and Samsung Electronics, remained at the second step. The reasons why they did not consider exporting to overseas markets seems to be a failure to meet an international competitive price and a lack of entrepreneurship.

In particular, Siltron underestimated the potential growth of the global PV market and so did not invest (Bae, 2009). Furthermore, it had difficulty in managing a solar cell production line in the 1990s, and disposed of its solar cell production line to Nesco Solar in 1997 in order to focus on producing wafers for semiconductors when the Asian financial crisis happened (Bae, 2009; MOCIE, 2003b).

3.2.4 Evolution of the PV Industry between the 1980s and 1990s

Since the 3rd and 4th Five Year Plans (1972-81), the Korean government and *chaebols* had made efforts to accomplish industrial upgrading mainly through the 'heavy and chemical industries programmes' as I discuss in sub-section VII.2.2.2. In terms of energy policy, a heavy and chemical industrialisation requires a stable and cheap energy supply, because they are energy-intensive. In the middle of the programme, however, the first and second oil shocks happened in 1973 and 1978, respectively. Thus, the Korean government established 'the Ministry of Energy and Resources (MOER)' in 1978 in order to cope with the energy problem during the process of industrial upgrading.

On the other hand, the institutional change that was more directly associated with the PV sector occurred in the second half of the 1980s. In order to reduce the dependency on imported oil, 'the Alternative Energy Development Promotion Act' was passed in 1987 through the involvement of MOER. Similarly to other selective industrial policies at that time, an alternative energy policy designated the PV sector as a priority sector through the National Project between 1989 and 1992. The most distinctive characteristic of the National Project was the participation of the company. Due to the participation of the firm, the project was significantly different from previous PV research such as a small-scale experiment in the laboratory. One of the main aims of the project was to begin the manufacture of silicon solar cells.

In fact, Siltron successfully completing a solar cell production line at 300 MWp of annual capacity was one of the achievements of the National Project. Indeed, this was the first silicon solar cell production facility in Korea. However, Siltron failed to commercialise its solar cells in the market place. The price of Siltron's solar cells was about double that of solar cells in the global market. At that time, the technological capability of the PV sector in Korea needed to learn more about advanced foreign PV technology, especially mass production technology. Due to this deficiency, Siltron could not export its solar cells. To make matters worse, the domestic PV market was stagnant, despite the fact that the demand-pull policy was introduced by the revision of the Alternative Energy Development Promotion Act. In other words, the government also failed to create sufficient demand to sustain the local PV production capacity. Eventually, facing the 1997 financial crisis, the first silicon solar cell production facility was shut down.

3.3 Emergence of PV firms: 2000s-

3.3.1 Adoption and Abolition of the Feed-in Tariff

3.3.1.1 Cooperation between the Two Advocacy Coalitions

From the 1990s, several environmental activist groups started to appear in Korea and gradually increased pressure on the government. Under the strong influence of the UNFCCC (United Nations Framework Convention on Climate Change), the 'Korean Federation for Environmental Movement (KFEM)' was launched as Korea's largest environmental organization by merging eight local environmental groups in 1993 (KFEM, 2009). In the next year, the 'Green Korea United (GKU)' was founded (GKU, 2009)[101]. In addition, the 'Korea NGO's Energy Network (KNEN)' was established to

[101] These two Non Governmental Organisations (NGOs), as representative civil environmental activists' groups in Korea, played a major role in enlightening and organising the Korean people to become more environmentally minded. Moreover, the 'Centre for Energy Alternative (CEA)' was established as a subsidiary of KFEM to oppose conventional energy, especially nuclear energy, as well as to expand alternative energy consumption by a bottom-up process in 2000

launch a voluntary and energy-saving movement as well as to support alternative energy (KNEN, 2009). These environmental groups have pressured the government to change energy policy to more environmental ones through forums, press releases, and demonstrations, etc. In particular, KFEM and KNEN were much involved in the introduction of the feed-in tariff in Korea.

Furthermore, industrial associations for alternative energy were also founded. At first, the 'Korea Small-hydro Generation Association' was founded in February 2001, and then it was enlarged and changed its name to the 'Korea New and Renewable Energy Association (KNREA)' in August 2001 (KNREA, 2009). This association has made great efforts to disseminate alternative energy policy through institutional changes and cooperation with the government, in particular with MOCIE.

The concept of 'advocacy coalitions', which is defined by Sabatier (1999)[102], is suitable for analysing the process of this cooperation in Korea. When this concept is applied to energy policy making in Korea, two advocacy coalitions can be identified: one is an industry-oriented coalition; the other is an environment-oriented coalition. Each coalition is composed of many groups as shown in Table VII-5.

Table VII-5 Two advocacy coalitions in energy policy making in Korea

	Industry-oriented Coalition	Environment-oriented Coalition
Ministry	Ministry of Commerce, Industry and Energy (MOCIE) Ministry of Planning and Budget (MOPB)	Ministry of Environment (ME)
Research Institute, Industry Association, and NGO	Korea Energy Economics Institute (KEEI) Korea Institute of Energy Research (KIER) Korea Electrotechnology Research Institute (KERI) Korea Energy Management Corporation (KEMC)	Korean Federation for Environmental Movement (KFEM) Green Korea United (GKU) Korea NGO's Energy Network (KNEN) Centre for Energy Alternative (CEA) Korea New and Renewable Energy Association (KNREA) Korea Photovoltaic Industry Association (KOPIA) Korea Solar Electric Power Association (KSEPA)

(CEA, 2009a).

102 Sabatier defines this concept as follows: '"[a]dvocacy coalitions," each composed of people from various governmental and private organizations that both (1) share a set of normative and causal beliefs and (2) engage in a nontrivial degree of coordinated activity over time' (Sabatier, 1999, p.120).
In addition, Jacobsson and Bergek (2004) use this concept to analyse the transformation energy sector (Jacobsson and Bergek, 2004).

Utility and Firm	Korea Electric Power Corporation (KEPCO)	Unison

Source: Author

The former concentrates on economic development by the creation and growth of new industries, while the latter prioritises protection of the environment and reduction of CO_2 emission over economic growth in an effect to fight global warming. In this sense, the industry-oriented coalition represents not a specific industry but a whole industry.

With regard to energy policy, whilst disputing some issues, the two coalitions have collaborated with each other on other issues. For example, concerning the nuclear policy, the industry-oriented coalition supported nuclear energy because it enabled industries to use electricity cheaply. However, the environment-oriented coalition opposed nuclear energy, pointing out the disposal problem of nuclear waste and high cost of nuclear energy in the long-term. On the other hand, they cooperated with each other with regard to the renewable energy support policy. The industry-oriented coalition expected this policy to play a decisive role in creating new renewable industry, while the environment-oriented coalition considered this policy to be effective in deploying renewable energy and cutting CO_2 emissions.

Each coalition expressed its opinion in the professional forums[103]. Finally, in December 2001, KEEI (Korea Energy Economics Institute) submitted to MOCIE a report called 'A Study on Building up Legal Institution for Disseminating New & Renewable Energy', which suggested introducing a feed-in tariff scheme in order to deploy renewable energy sources substantially. KERI, KEMC, KNEN, KFEM, Unison and KIER participated in this study as advisors and co-authors (KEEI, 2001). Thus, this study was the result of the collaboration of the two advocacy coalitions. The industry-

[103] In September 1998, KFEM hosted the 'Renewable Energy Symposium', in which main discussions were as follows: nuclear energy was not the answer for sustainable energy system; renewable energy could be one of the solutions for future energy systems; and current energy policy was not sufficient to form renewable energy market (KFEM, 1998). In July 2001, MOCIE hosted the 'Great Discussion for Accelerating Deployment of Renewable Energy', in which Unison, a wind turbine company, KFEM, KEEI, KIER, and KERI (Korea Electrotechnology Research Institute) took part. In this discussion, the feed-in tariffs was suggested officially for renewable support policy for the first time in Korea (MOCIE, 2001). In September 2001, CEA and KNEN co-hosted the 'Renewable Energy Promotion Act Forum', in which they claimed that the coming revision of the Promotion Act be more promotional to renewable energy markets (CEA, 2009b).

oriented coalition, MOCIE, KEMC, KERI, and KIER wished to adopt the feed-in tariff in order to boost the domestic PV industry as well as other renewable industries. On the other hand, the environment-oriented coalition, KFEM, KNEN, and Unison wished to adopt the feed-in tariff in order to deploy PV energy as well as other renewable energies.

In the process of revising the Act, there was some opposition to the introduction of the feed-in tariff. In particular, the Ministry of Planning and Budget (MOPB) strongly opposed the introduction of the feed-in tariff at first because MOPB thought the feed-in tariff a too generous subsidy for renewable energies. However, MOCIE explained to MOPB the urgency of deployment of renewable energies putting forward the cases of Germany, Japan and Spain. Moreover, NGOs persuaded higher executives in MOPB directly to help with the adoption of the feed-in tariff. During the deliberation process of the National Assembly, NGOs and members of the National Assembly who agreed on the draft Act persuaded other members of the National Assembly who disagreed with it (Lee, 2009). Finally, the feed-in tariff was adopted mainly due to the cooperative efforts made by the two coalitions.

3.3.1.2 Adoption of the Feed-in Tariff

In March 2002, the Alternative Energy Development and Deployment Promotion Act (AEDDPA) was revised to add the feed-in tariff provision. As MOCIE announced the instructions of the 'Standard Price of Electricity Generated by Alternative Energy' on 29th May 2002, the feed-in tariff was implemented for the first time in Korea (MOCIE, 2002). Table VII-6 shows us the feed-in rates (standard prices) in these instructions.

Table VII-6 Feed-in rates in Korea in 2002

	Standard Price (KW/kWh)		
	For private use	For business	
Photovoltaic	716.40		
Wind	SMP+CP*	107.66	
Small hydro	SMP+CP	73.69	
Gas from waste	SMP+CP	~ 20 MW	65.20
		20 ~ 50 MW	61.80
Incineration of waste	SMP+CP		

Source: MOCIE Press Release on 29th May 2002

*SMP(System Marginal Price) + CP(Capacity Price)

The standard price for PV electriciy (716.40KW/kWh) was decided by consideration of the price of the German feed-in tariff (597KW (0.99Mark)/kWh, using the average currency exchange rate in October 2001). The standard price for PV electricity was fifteen times higher compared to the average transaction price electricity of 48.80 KW/kWh in 2001 (MOCIE, 2002). This was a huge demand-pull policy which could create a large amount of domestic demand for PV systems, and can be stated as being a significant ‘institutional change’ going to the heart of the process whereby new technologies gain ground (Freeman and Louça, 2002 cited in Jacobsson and Bergek, 2004).

The main goals of introducing the feed-in tariff were dealing with UNFCCC, diversification of energy sources, and creating next generation renewable industries. In other words, the goals were development of renewable industries and deployment of renewable energies. At that time, these two goals harmonised well without serious conflict, because the industry-oriented coalition also prioritised deployment of renewable energies in order to meet their target by 2006 (Lee, 2009). As time went by and subsidy grew, disputes over which goals were more important occurred between the two advocacy coalitions, as I will describe below.

3.3.1.3 Domestic Market Explosion and Import Penetration

The domestic demand for photovoltaic systems was still stagnant until 2003, despite the feed-in tariff implemented from 2002. Thus, it took over two years from their introduction for the feed-in tariff to become effective. This duration can be explained by an administrative time lag which includes local governments’ recognition of the new scheme, adaptation to it, setting further detail processes of permission, etc. In fact, in the case of the first commercial PV power plant, it took about two years to get permission from the local government (Heo, 2009).

However, since the first commercial PV power plant (New Sun Energy, 200kWp) was constructed in September 2004, the average annual growth rate of PV installed was about 280% between 2004 and 2008, although some decrease happened in 2009 (KNREC, 2009). Figure VII-6 and Table VII-7 illustrate the domestic market expansion.

Figure VII-6 Annual PV installed in Korea, 2002-2009 (unit: MWp)

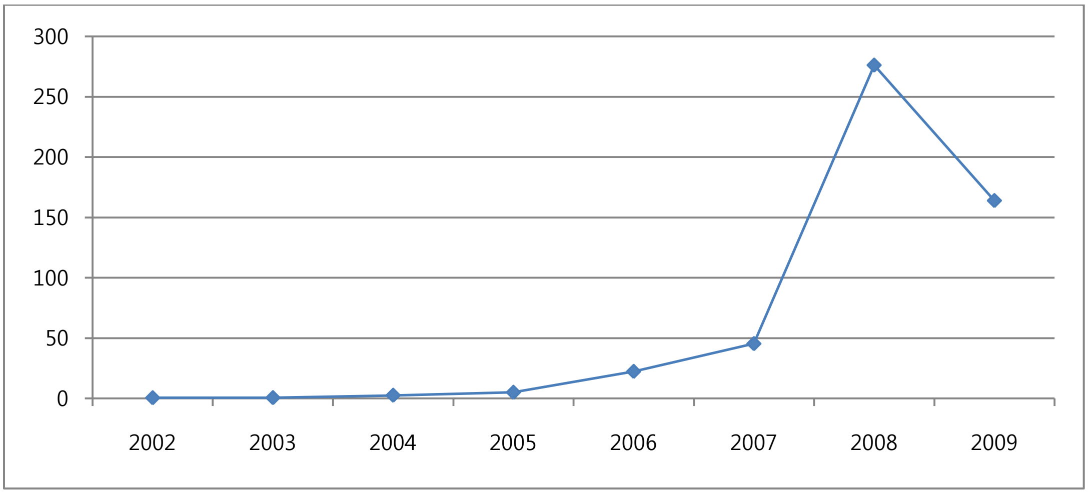


Table VII-7 Annual PV installed in Korea, 2002-2009 (unit: MWp)

Year	2002	2003	2004	2005	2006	2007	2008	2009
MWp (%)*	0.475 (-40)	0.563 (19)	2.553 (353)	4.99 (95)	22.32 (347)	45.35 (103)	276.3 (509)	164 (-40)

Source: Photovoltaics Support Policy and Industry (KNREC, 2009)

*Annual growth rate

This expansion of the domestic market was the effect of mixed demand-pull policies such as the rooftop programme, subsidies for local governments and the regulation of public agencies until 2005. However, the effect of the feed-in tariff has been distinctive since 2006, as you can see in Table VII-8. The share of installation through the feed-in tariff compared to total PV installed surpassed other policy's shares from 2006, and became the dominant contributor to PV installation, reaching 93% in 2008.

Table VII-8 Contributions of demand-pull policies to annual PV installed (unit: kWp)

Year	2004	2005	2006	2007	2008
Feed-in tariffs (%)*	200 (8)	1,143 (23)	9,012 (40)	28,842 (64)	257,499 (93)
Rooftop program (%)*	625 (25)	2,340 (47)	6,573 (29)	8,341 (18)	9,579 (4)
Etc (%)*	1,728 (67)	1,507 (30)	6,737 (31)	8,164 (18)	9,246 (3)
Total (%)	2,553 (100)	4,990 (100)	22,322 (100)	45,347 (100)	276,324 (100)

Source: Photovoltaics Support Policy and Industry (KNREC, 2009)

*Share of total PV installed

In short, demand-pull policies which were introduced since 2002 have been effective in increasing the domestic demand for PV systems. In particular, the feed-in tariff played a major role in expanding the domestic demand. Therefore, the feed-in tariff, as a representative demand-pull policy, was successful in deploying PV electricity.

On the other hand, the domestic demand explosion without sufficient local production capacity, as I will discuss later, resulted in the rapid increase of imported PV cells and modules. Figure VII-7 and Table VII-9 show us how fast the importation of PV cells and modules increased between 2003 and 2008.

Figure VII-7 Import of PV in Korea, 2003-2009 (unit: USD million)

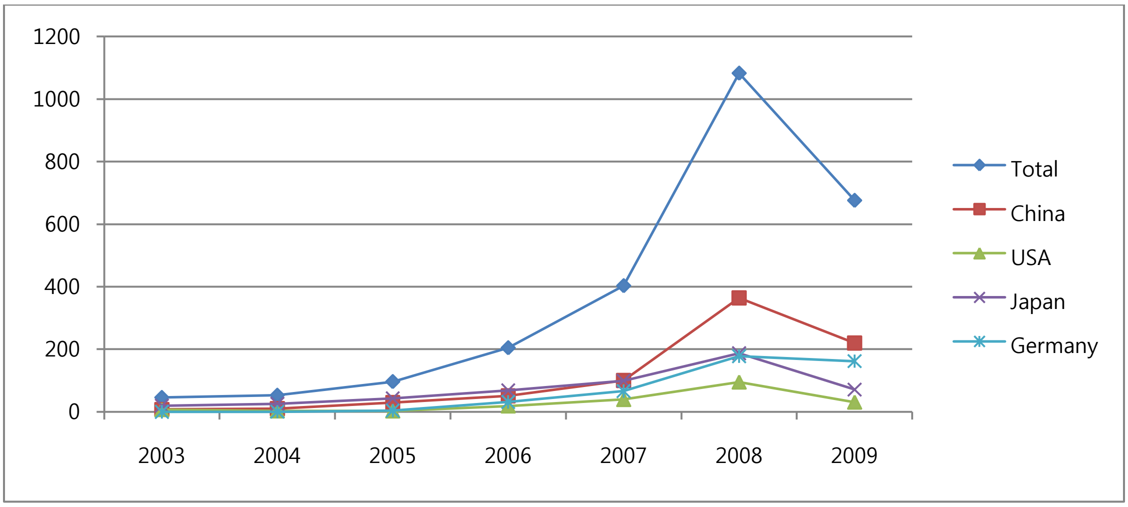


Table VII-9 Import of PV cells and modules in Korea, 2003-2009 (unit: USD million)

	2003	2004	2005	2006	2007	2008	2009
China (%)*	8 (57)	10 (25)	30 (200)	51 (70)	100 (96)	364 (264)	220 (-40)
Japan (%)*	20 (-6)	25 (25)	43 (72)	69 (60)	99 (43)	187 (89)	71 (-62)
Germany (%)*	0.04 (290)	0.3 (650)	4 (1,233)	31 (675)	67 (116)	178 (166)	162 (-9)
USA (%)*	7 (92)	3 (-57)	3 (0)	19 (533)	39 (105)	95 (144)	31 (-67)
Total (%)	46 (16)	53 (15)	97 (83)	205 (111)	403 (97)	1,083 (169)	676 (-38)

Source: Trade Database of KITA (Korea International Trade Association), (http://www.kita.net/: required to log in), searched by HSK 8541.40.9020[104]

[104] In terms of HS (Harmonized Commodity Description and Coding System), photovoltaic cells/modules are included in the code of ‘8541.40’ which is described as ‘photosensitive semiconductor devices; light emitting diodes’. In particular, HSK (Harmonized System of Korea) adopts 10-digit category. In HSK, photovoltaic cells/modules are included code of ‘8541.40.9020’ which is described as ‘photovoltaic cell (includes solar cell, photo diode, photo couple and photo relay; solar module and solar panel)’. Photo diode is a kind of sensor to

*Annual growth rate

According to trade data, imports from China increased faster than those from any other country.

When we look at other sets of data, the origins of PV modules in PV power plants and rooftops also reveal how much imported modules were installed in Korea, as shown in Figure VII-8 and Table VII-10.

Figure VII-8 Origins of PV modules in PV plants and rooftops in Korea (unit: kWp)

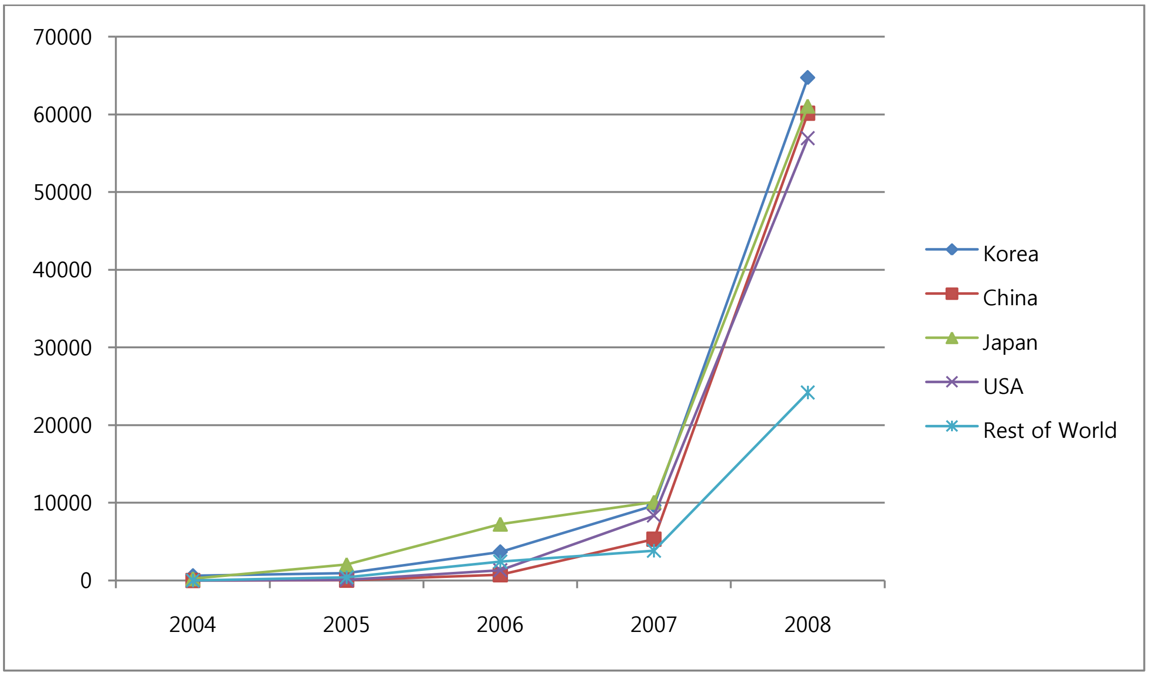


Table VII-10 Origins of PV modules in PV plants and rooftops in Korea (unit: kWp)

	2004	2005	2006	2007	2008
Korea (%)*	595 (72%)	928 (27%)	3,666 (24%)	9,640 (25%)	64,731 (24%)
China (%)*	0	34 (1%)	746 (5%)	5,304 (14%)	60,152 (23%)
Japan (%)*	230 (28%)	2,036 (58%)	7,250 (47%)	11,082 (29%)	61,062 (23%)
USA (%)*	0	72 (2%)	1,308 (8%)	8,342 (22%)	56,949 (21%)
Rest of World	0	415	2,415	3,814	24,201

recognise light. Photo couple and photo relay are a kind of electrical currents controller like a switch. They are usually used as parts of electronics. "The trade volume of them is small enough to ignore compared to solar photovoltaic cells and modules" (Kang, 2009).

(%)*		(12%)	(16%)	(10%)	(9%)
Total	825 (100%)	3,485 (100%)	15,385 (100%)	38,182 (100%)	267,095 (100%)

Source: Photovoltaics Support Policy and Industry (KNREC, 2009)

*The shares in total

According to Table VII-10, the market share of Korean modules in the domestic market fell from 72% to 24% between 2004 and 2008, whilst that of imported modules rose from 28% to 76% in the same period. As a consequence, the high contributions of imported modules to PV systems installed in Korea caused some criticism against the feed-in tariffs in view of industrial policy, even though the local production of PV modules also increased very fast.

3.3.1.4 From FIT to RPS: Conflicts between the Two Advocacy Coalitions

After the introduction of the feed-in tariff, cooperation between the two coalitions continued well for several years. In 2003, MOCIE extended the guaranteed period for the feed-in tariff from 5 years to 15 years and introduced a market cap scheme of 20MWp (MOCIE, 2003a). In 2004, MOCIE introduced a new regulation that forced new government and local government buildings, and public agencies to install alternative energy systems such as PV, solar thermal, and geo-thermal systems (MOCIE, 2004a).

However, this short-lived collaboration between the two advocacy coalitions came to an end in 2006. On 23rd March 2006, the hearing for a revision of standard price was held in COEX in Seoul. The environment-oriented coalition opposed a reduction of the standard price, while the industry-oriented coalition suggested a draft of revision in favour of a reduction of price (Jung, 2006). MOCIE proposed that the standard price of PV electricity be reduced in accordance with an analysis of the revenue of generators within the period. Though generators opposed MOCIE's proposal on the basis of the domestic market's infancy (Jung, 2006), MOCIE finally revised the 'Standard Prices of Renewable Electricity' in October 2006. The price for PV electricity decreased from 716.40 KW/kWh to 711.25 (under 30kWp) and 677.38 (over 30kWp) (MOCIE, 2006). The reasons of the industrial-oriented coalition for the revision were as follows: firstly, it was forced to revise the standard price of renewable electricity before the end of the five-year enforcement period by the 'Standard Price of Electricity Generated by Alternative Energy'; secondly, the price of PV systems fell from 15 m. KW (approx. 15,000 USD)/kWp to 9.4 m. KW/kWp between 2003 and 2006 through technological innovation (Kim, 2009).

In 2008, conflict between the two coalitions became more serious after the Ministry of Knowledge Economy (MKE, previously MOCIE) suggested further reduction of the standard price. In fact, the amount spent on feed-in renewable generators since 2008 went substantially beyond the estimated budget. In particular, the budget spent in 2009 was seven times as high as the budget estimated in 2006. Table VII-11 reveals the differences between the budgets estimated and spent.

Table VII-11 Budgets estimated and spent (unit: KW billion; approx. USD million)

	2002	2003	2004	2005	2006	2007	2008	2009
Estimated	3.3	5.63	14.66	25.99	34.47	-	-	-
Spent	3.3	5.58	5.08	7.55	9.97	26.82	119.73	233.0

Source: MOCIE (2002) and KNREC (2009)

In particular, the government estimated that the budget for the feed-in tariff would reach 213 billion KW (approx. 213 million USD) in 2011 (MOFE, 2008). Furthermore, the government recognised that most budgets for the feed-in tariff resulted in the rapid increase of imported PV modules rather than the development of the local PV industry. Therefore, the Korean government suggested not only a reduction in the standard price of PV electricity but also a change in policy from the feed-in tariff to the Renewable Portfolio Standard[105] (RPS).

Many environmental civil activist groups, together with the PV generators strongly criticised the government's inconsistency of policy and claimed that the government

105 The Renewable Portfolio Standard (RPS) is another scheme to deploy renewable energy resources. RPS enforces electricity generators to produce a certain ratio of their electricity from renewable energy resources. Whereas the feed-in tariff (FIT) scheme is regulation of price, RPS is regulation of quantity. Thus, RPS is more market-oriented than FIT, because the price of renewable electricity is determined by the market. RPS has been adopted in many of the states in the US and had been adoped in the UK. It is argued that RPS is less effective in deploying renewable energy than FIT (Mitchell et al., 2006).

should withdraw the draft for revision (Jung, 2008). Finally, the standard price of PV electricity decreased from 677.38 KW/kWh to 590.87 (option 15-year) and 536.04 (option 20-year). However, a market cap was allocated 50, 70, and 80 MWp in 2009, 2010 and 2011, respectively[106], and the RPS to be introduced in 2012 (MKE, 2008).

3.3.2 Start-up of the PV Industry

3.3.2.1 Global Market Explosion

Due to European countries' demand-pull policies, mainly the German feed-in tariff, and the US tax incentives, the global PV market has sky-rocketed since 2000. The average annual growth rate was around 50% between 2001 and 2009, as you can see Figure VII-9 and Table VII-12.

Figure VII-9 Annual PV installed in the world, 2000-2009 (unit: MWp)

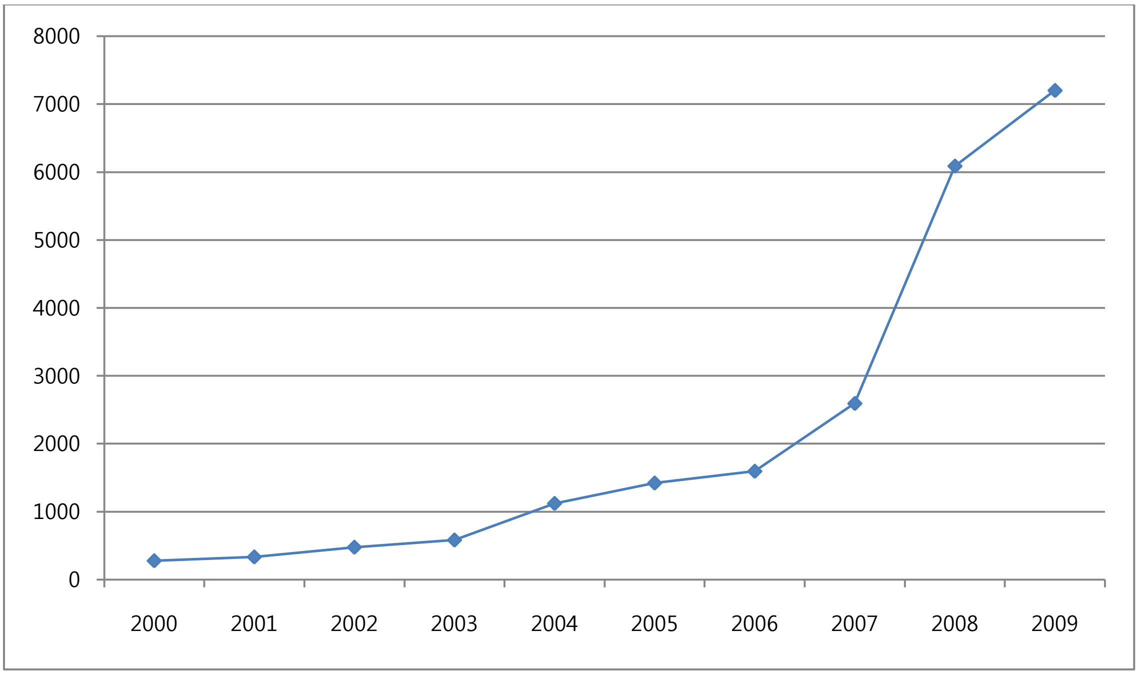


Table VII-12 Annual PV installed in the world, 2000-2009 (unit: MWp)

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
MWp	278	334	477	583	1,122	1,422	1,596	2,594	6,090	7,203

[106] Thus, the amount of PV system which can be applied to the feed-in rate is only 50 MWp in 2009.

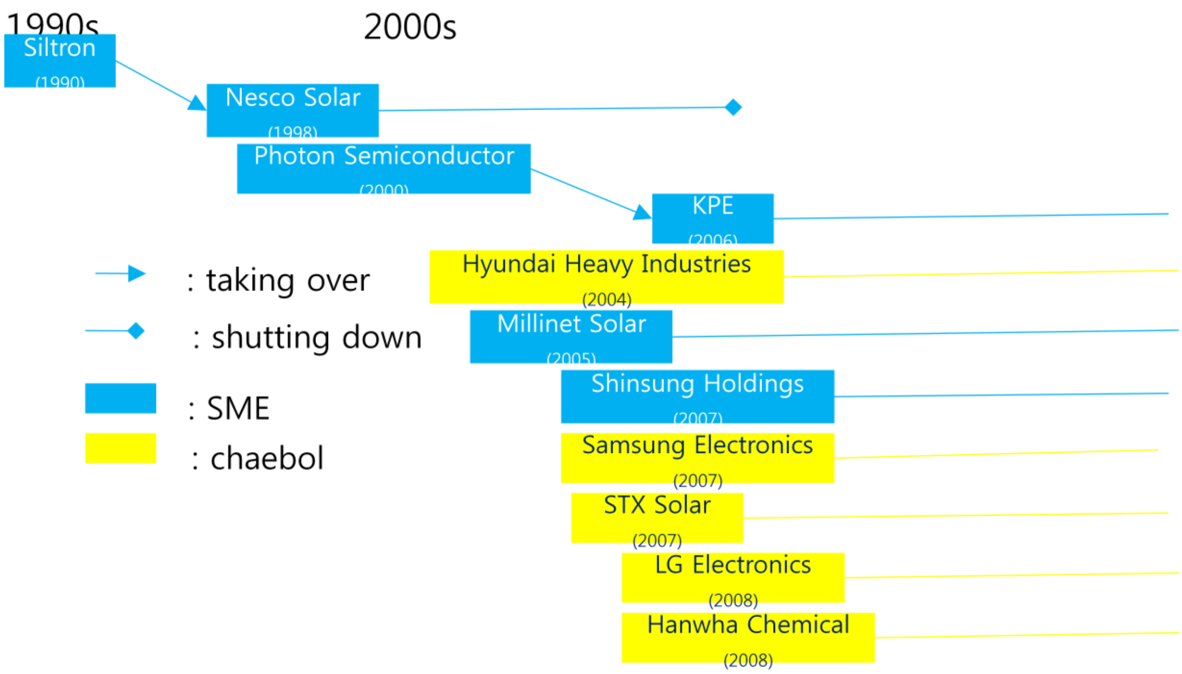
(%)*		(20)	(43)	(22)	(92)	(27)	(12)	(63)	(135)	(18)

Source: Global Market Outlook 2010 (EPIA, 2010)

*Annual growth rate

This growth of the global PV market influenced not only foreign companies but also Korean companies. Since the late 1990s, the Korean solar cell companies entered into the PV industry, as shown in Figure VII-10. In particular, after the PV market became brighter than before, most of the *chaebols* such as Samsung, LG, and Hyundai participated in the rush for the PV industry.

Figure VII-10 Entry of Korean companies into the PV cell industry



Source: Interviews and each firm’s website

SME (Small and Medium-sized Enterprise)

3.3.2.2 Entry of SMEs

3.3.2.2.1 Rapid Response to the Market Expansion

Responding to global market expansion, Nesco Solar and Photon Semiconductor entered into the PV industry in 1998 and 2000, respectively, as shown in Figure VII-10.

They were small and new companies. Nesco Solar was founded as a joint venture between three Korean companies and a Canadian company. It began with taking over the cell production facility of Siltron in 1998 and completed the pilot cell production line at the annual capacity of 2MWp in 2002 (Bae, 2009). On the other hand, Photon Semiconductor was founded as a laboratory venture in *Sungkyunkwan* University, and also completed the pilot cell production line at the annual capacity of 2MWp in 2002 (Lee, J., 2010).

According to Malerba and Orsenigo (1997), there are two types of firm entry into new markets: one is a new entry, and the other is a lateral entry. The new entry is the birth of a new firm, while the lateral entry is a diversification of existing firms. Moreover, most new entrants are small firms, while most lateral entrants are large firms (Malerba and Orsenigo, 1997).

From this respect, Nesco Solar and Photon Semiconductor can be categorised as new entrants because they were Small and Medium-sized Enterprises (SMEs) and their entries were 'births of new firms'. By contrast, Samsung Electronics, LG Electronics and Hyundai Heavy Industries can be categorised as lateral entrants because they were *chaebols*, large business groups, and their entries were a type of 'diversification of their business areas'.

However, the former was prompt to respond to the market, while the latter was late to do so. One of the reasons why the former was faster than the latter is that the PV market was still risky and uncertain in the late 1990s and the early 2000s. Another reason might be associated with the venture boom in the early 2000s in Korea. After the 1997 financial crisis, the Korean government nurtured venture businesses as an alternative engine of growth, as I mention in sub-section VII.2.3.2 (p. 178). In fact, Photon Semiconductor was provided with 50 million KW (approx. 50,000 USD) in 2001 by the government promotion programme of venture businesses (Lee, J., 2010).

Thus, at the starting point of the PV industry in the early 2000s, the Korean PV industry seems to be more advanced than the Chinese PV industry. To illustrate this, Photon Semiconductor was visited by the engineers of Yingli in order for them to learn about PV technology (Lee, P., 2010).

3.3.2.2.2 Difficulties in Financing and Rapid Expansion

Unlike in the German and Chinese cases, the Korean solar cell companies failed to expand their production capacity rapidly in the first half of the 2000s. As shown in Table VII-13, Nesco Solar did not expand its production capacity any more. Finally, it shut down in 2006. On the other hand, Photon Semiconductor made a success in constructing a mass production line at 5MWp of annual production capacity in December 2003. However, it did not expand its capacity until it was taken over by the KPE in 2006.

Table VII-13 Production capacity of Nesco Solar and Photon Semiconductor (unit: MWp)

	2002	2003	2004	2005	2006	2007	2008	2009
Nesco	2				closed			
Photon	2	5			30*			60

Source: Interviews

* Since 2006, Photon Semiconductor was taken over by the KPE

At this time, it was said that the minimum efficient scale of a solar cell production line was at least 30 MWp of annual capacity. This scale of investment required at least 30 billion KW (approx. 30 million USD) excluding the land costs. However, it was too large an amount of investment for SMEs to finance in the Korean economy. Firstly, the Korean government support for new industries such as policy loans in the 1970s and 1980s has not existed since the 1990s. Secondly, it was difficult for SMEs to obtain a loan from the banks without security such as land. Thirdly, it was not easy for SMEs to access the stock market because the market still regarded the PV sector as risky in the first half of the 2000s. Therefore, there was no way for SMEs to raise a fund to invest in such a scale of production line.

Furthermore, most of the solar cell production equipment had to be imported from more advanced countries due to the lower level of technology of the Korean equipment sector. Due to the difficulties of SMEs, Nesco Solar finally shut down and key persons moved to Hanwha Chemical (Bae, 2009). Also, Photon Semiconductor was taken over by KPE (a medium-sized enterprise) in 2006.

3.3.2.3 Late Entry of the *Chaebols*

3.3.2.3.1 Reasons for Late Entry

Since 2004, the German market exploded due to the feed-in tariff scheme as I discuss earlier (V.3.3.1 p. 96). Mainly due to the growth of the German market, the annual growth rate of the global PV market reached 92 per cent as shown in Table VII-12 (p. 205). Thus, the global PV market was worth more than an annual 5 billion Euros at that time. Moreover, the market expectations of the PV industry changed from uncertain to optimistic because of the rapid growth of PV markets and the increase of feed-in tariff schemes mainly in European countries.

As these changes revealed a brighter future, Korean business groups started to jump on the bandwagon. In 2004, Hyundai Heavy Industries (HHI) launched a new energy team in order to enter into the PV industry. In 2005, Millinet Solar established itself as a new entry into the solar cell industry. In 2007, Samsung Electronics[107], STX Solar, and Shinsung Holdings entered, as did LG Electronics and Hanhwa Chemical in 2008. Most of these, including Hyundai, Samsung, STX, LG and Hanhwa, were *chaebols* as shown in Table VII-14.

Table VII-14 General information about the *chaebols* which entered into the PV industry

	Year of establishment	Main items	Sales in 2008 (unit: billion KW)	Number of employer in 2008
HHI	1970	Shipbuilding, engine	19,957	25,000
Samsung Electronics	1969	Semiconductor, mobile phone	73,000	69,000
STX Group*	1976	Shipbuilding, shipping	23,800	46,800
LG Electronics	1958	Mobile phone, electronics	27,638	28,659
Hanhwa Chemical	1965	PE, PVC	3,037	-

Source: Website of each firm

[107] In fact, Samsung Electronics has engaged in solar business (module part) since 1992. Its entry looked like trials and experiments towards new businesses in order to diversify its business area. However, the domestic demand for PV systems was very limited in the 1990s, thus a solar business team of Samsung Electronics spun off as a manufacturer of solar modules, S-Energy, in 2001 (S-Energy, 2009).

* STX Solar is a subsidiary of STX Group

The *chaebols*' entries were late compared with the SMEs' entries as well as those of foreign big companies such as Sharp, Siemens, BP, etc. According to interviews, the reasons for their late entries can be explained as follows: firstly, the market size of the PV industry was not sufficient to achieve economies of scale in the first half of the 2000s; secondly, the PV market was heavily dependent on government policy such as the feed-in tariff, thus *chaebols* regarded the PV market as risky and unattractive; thirdly, the level of technological capability of the Korean PV sector was lower than that of more advanced countries.

The first reason is connected to a 'defensive innovation strategy' rather than an 'offensive strategy' by the Korean *chaebols* during the industrialisation process (Freeman and Soete, 1997). If I follow this theory, then *chaebols* appeared to choose a defensive strategy in the PV sector. In other words, they did not wish to be the first in the world, because they did not wish to take the high risks of being the first. Rather, they preferred to follow, so that they could learn and profit from the mistakes of those first movers (Freeman and Soete, 1997). However, considering the efforts of the *chaebols* in being the first in many sectors regardless of risks, this reason does not fully explain the late entry.

The second reason is likely to be associated with the *chaebols* distrust of the consistency of government policy. They were concerned that the PV market could shrink when government policy changed. However, considering the urgency of the climate change issue and the pressure to establish a sustainable energy system, it was difficult for major countries such as Germany to change government policy against the PV industry. Moreover, most new industries are often provided with support from the government in their initial period. Thus, the second reason does not fully explain it, either.

The third reason is correct in that the PV research pools were not sufficient and there were fewer local PV equipment suppliers than in more advanced countries such as Germany and Japan. However, considering the catching-up process of the semiconductor industry, they were not prerequisites for manufacturing. In fact, in the

Korean semiconductor industry, manufacturers grew first and the growth of local equipment suppliers followed. Furthermore, it is said that the technical barrier of developing silicon solar cells is not higher than that of the semiconductor. Thus, the third reason is not a comprehensive explanation, either.

The most important reason is likely to lie in the Korean political economy during the first half of 2000s. After the 1997 crisis, the Korean government implemented restructuring programmes in the financial and corporate sectors, as I discuss in sub-section VII.2.3.2. For example, the government enforced the reduction of the debt-equity ratio of *chaebols* and regulated internal transactions within the business groups. Furthermore, the Big Deal, which meant business swaps among the top five *chaebols* in industries with over-capacity, were enforced by the government in order to make the *chaebols* concentrate their resources on the sectors of their core competence (Shin and Chang, 2003). As a consequence, *chaebols* seemed to have no room to invest in new sectors such as a PV industry. They concentrated on their core sectors such as the semiconductor and shipbuilding industries, even though many reports pointed out the lack of alternative engines of future growth (SERI, 2002). In fact, *chaebols* did not invest much in the solar cell industry until 2008.

3.3.2.3.2 The Strategy of *Chaebols*

Although the start of solar-cell manufacture by *chaebols* was later than that of bigger, more advanced companies, they have been catching up with more advanced companies swiftly utilising their advantage of business groups. Firstly, they seem to have no difficulty in mobilising capital for investment. Considering their level of sales and ability to raise funds through direct and indirect financing, the amount of investment required for a minimum efficient production line of solar cells was not too demanding for them. Secondly, they have a high concentration of skilled personnel within the solar cell business unit, bringing relevant scientists and engineers together from within business groups or from the outside. For example, Samsung Electronics gathered PV scientists and engineers from Samsung SDI and Samsung Advanced Institute of Technology. Also, LG Electronics acquired the solar cell team from LG Chemical, and Hanhwa Chemical brought key persons from Nesco Solar into its solar team. Thirdly, they have utilised their brand names and marketing channels to export their products.

They have expanded their production capacity swiftly, as shown in Figure VII-11 and Table VII-15. In fact, the total annual production capacity of silicon solar cells was nearly 2 GWp at the end of 2010. While most of them expanded by the construction of their factories and production facilities, Hanhwa expanded faster than any other firm through the acquisition of Solarfun, the fourth largest Chinese PV firm which had a 500MWp of annual production capacity.

Figure VII-11 Annual production capacity of silicon cells in Korea (unit: MWp)

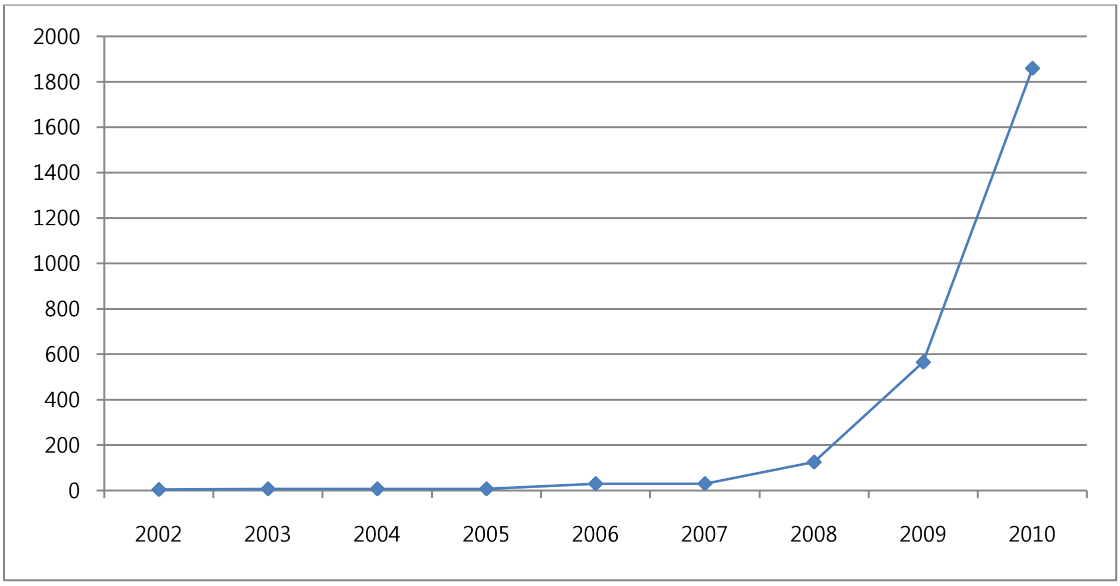


Table VII-15 Annual production capacity of silicon cells in Korea (unit: MWp)

	2002	2003	2004	2005	2006	2007	2008	2009	2010*
Nesco	2	2	2	2					
Photon	2	5	5	5	30	30	30	90	90
HHI							15	70	400
Millinet							30	100	300
Shinsung							50	100	150
Samsung								30	100
LG								120	240
STX								25	50
Hanhwa								30	530**
Total	4	7	7	7	30	30	125	565	1,860

Source: Interviews and website of each firm

* Estimation in September 2010

** Hanhwa took over Solarfun, China’s fourth largest producer of PV, in September 2010

Moreover, they have attempted to complete vertical integration within the silicon solar cell value chain. For the first time in Korea since 2010, HHI have completed vertical integration from poly-silicon to silicon solar modules. Following HHI, Hanhwa Chemical accomplished the vertical integration from ingot/wafer to modules and planned to construct a poly-silicon production facility. Samsung and LG also made an effort to complete a vertical integration, as shown in Table VII-16.

Table VII-16 Vertical integration in the Korean PV industry

	HHI	Samsung	LG	Hanhwa
Poly silicon	Production since 2010 (KAM) (JV with KCC)*	Starting (Samsung Fine Chemicals) (JV with MEMC)**	Considering (LG Chemical)	Planning
Ingot/wafer				Production since 2010
Cell	Production since 2008	Production since 2009	Production since 2009	Production since 2009
Module	Production since 2004		Production since 2009	Production since 2010

Source: Korean newspapers (The Korea Energy News; Energy & Environment News)

* KAM (Korea Applied Material): HHI has 49 per cent of shares of KAM

** Samsung Fine Chemicals and MEMC have 50 per cent of shares of the JV, respectively. MEMC is an American poly silicon manufacturer

On the other hand, local solar cell equipment suppliers grew along with the growth of the production capacity of *chaebols*. At first, *chaebols* imported PV equipment from advanced foreign companies such as Centrotherm GmbH, Roth and Rau AG, and Schmid GmbH by turn-key projects. As they experienced expansion of production lines, they increased the ratio of supply from local equipment suppliers. For example, HHI contracted with Shinsung ENG to construct a second production line in 2009. Shinsung ENG, which originally constructed semiconductor equipment, is a subsidiary of Shinsung Holdings, which reduced the construction time of a 30MWp production line from 18 months to 3 months.

In short, the Korean PV industry started up later than the German and Chinese ones, however, it grew fast in the late 2000s in order to compensate for its late entry.

3.3.3 Evolution of the PV Industry in the 2000s

From the late 1980s, under the global trend of neo-liberalism, the Korean political economy began to model itself on the Anglo-American economic system. During this process, there occurred the financial crisis of 1997, following this dismantling of the developmental state and the strengthening of the *chaebols*' under the 'restructuring programme'. It no longer seemed possible for the Korean government to implement any kind of selective industrial policy. On the other hand, the climate change issue has become influential since the 1990s, and under these new international circumstances, environmental activist groups have emerged and strengthened their pressure on the government. Due to collaboration between the environment-oriented coalition and industry-oriented coalition, the feed-in tariff scheme was adopted in 2002. Indeed, this was a landmark development for the PV sector in Korea.

Similarly to the German case, the feed-in tariff scheme resulted in the expansion of the domestic PV market. However, in contrast to the German case, the local PV industry was not established even despite the remarkable growth of the domestic PV market. As a consequence, imports of PV modules substituted for the growth of local PV firms. This caused criticism to grow against the feed-in tariffs, especially in the Ministry of Planning and Budget. Furthermore, the budget spent on feeding renewable generators was far beyond the level expected. Therefore, the government changed the renewable energy support scheme from the feed-in tariff to the renewable portfolio standard disregarding strong criticism from the environment-oriented coalition.

On the other hand, although the domestic PV market grew after the introduction of the feed-in tariffs, the PV companies, especially silicon solar cell firms, did not enter into the PV sector in the first half of the 2000s. Most of the large Korean firms, *chaebols*, were late to respond to the emerging PV market because they were under the restructuring programme of the corporate sector after the 1997 crisis. They were unlikely to have time to find new businesses due to a concentration on their core businesses. In addition, most of the SMEs were too weak to invest in solar cell production lines aggressively. Thus, the Korean PV industry did not have a sufficient production capacity to cover the expansion of the domestic market. Only after the government loosened the reigns of the *chaebols*, did they start to find alternative engines of growth. In fact, since 2008 *chaebols* have started to expand the solar cell production capacity utilising their advantages of business groups.

4. IMPACT OF INSTITUTIONAL ADVANTAGE ON THE NECESSARY FUNCTIONS

Like the two previous chapters (V and VI), in this section, I shall examine the inter-relationship between institutional advantages of the Korean political economy and the three necessary functions for the development of the Korean PV industry: market formation; capital mobilisation; process innovation.

4.1 Market Formation

Although ‘the Alternative Energy Development and Deployment Promotion Act’ was revised to create renewable energy markets in 1997, the demand-pull policy did not effective until the 2000s. In 2002, the feed-in tariff was adopted by the cooperation between the industry-oriented coalition and the environment-oriented coalition. After that, the domestic PV market exploded due to this policy, as described in sub-section VII.3.3.1.3 (p. 200). Thus, it can be evaluated that the Korean government succeeded in creating a substantial domestic PV market like the German case.

However, unlike the German case, the domestic PV industry was not established, responding to the growth of the domestic PV market. The Korean government attempted to facilitate to develop a domestic PV industry by building an institutional advantage in terms of market formation. Despite this institutional advantage, the domestic PV industry did not grow fast in Korea. Why did the PV industry in Korea not grow as had happened in Germany under the same condition of the feed-in tariff? In order to solve this question other factors will be examined in the next sub-section.

4.2 Capital Mobilisation

As I discuss in the German and Chinese case, capital mobilisation is an essential function for a development of the PV industry, because the PV industry is a capital-intensive industry. Furthermore, in the 2000s, capital mobilisation became more important, because it was the best strategy for c-Si cell firms to achieve economies of scale through rapid expansion of production capacity.

Since the 1990s, the developmental-state characteristic of the Korean political economy such as the state-banks-*chaebols* nexus has been dismantled under the name of liberalisation of the political economy. In particular, after the 1997 crisis, the ability of risk taking of the Korean economic system was significantly weakened in investing new industries.

Without government support such as policy loans, it was difficult for SMEs to raise funds from the banks or stock market. Thus, early PV starters (Nesco Solar and Photon Semiconductor) failed to mobilise capital to invest. Furthermore, *chaebols* had no room to invest in new sectors because they had no choice but to concentrate their core competence under the restructuring programmes.

Therefore, the Korean PV industry missed the chance to respond the expansion of domestic PV market and global market unlike Germany and China. This was mainly because Korea had an institutional disadvantage in mobilising capital in a new sector, especially in the 2000s.

4.3 Process Innovation

As in China, technological learning has been at the heart of the industrialisation in Korea, because Korea fell behind more advanced countries in terms of innovation. Thus, Korean PV firms have attempted to catch up with foreign leading companies mainly through importation of cutting-edge equipment from more advanced countries, like China.

Moreover, the well-developed semiconductor equipment industry provides potential for development of a PV equipment industry in Korea, because they are close to each other in terms of production processes. Indeed, Shinsung Holdings, a medium-sized enterprise which originally produced semiconductor equipment, achieved 19 per cent of conversion efficiency of mono c-Si cells in November 2010 (Shinsung Holdings, 2010).

Furthermore, *chaebols* have strength in R&D through internal human resourcing, as described as one of institutional advantage in terms of innovation in sub-section VII.2.2.2. In fact, Samsung Electronics and LG Electronics brought scientists and engineers who were involved with PV technology together into their PV business units in the 2000s.

As a consequence, the Korean PV industry is catching-up with advanced countries in terms of thickness of wafer and conversion efficiency of solar cells, as shown in Table VII-17 and Table VII-18.

Table VII-17 Decrease of wafer thickness (unit: μm)

	2003	2004	2005	2006	2007	2008
Millinet Solar						200
Shinsung						200

Source: Each firm's annual report

Table VII-18 Cell efficiency of the new generation of PV firms in Korea (unit: %)

		2004	2005	2006	2007	2008	2009	2010
Millinet Solar	Poly					15	16.2	18
Shinsung	Mono					16	17.4	19
	Poly							17.2

Source: Each firm's annual report and press release

Poly: Poly crystalline silicon cells

Mono: Mono crystalline silicon cells

5. CHAPTER SUMMARY

This chapter has aimed to explain the development of the Korean PV industry in the context of Korean political economy. In the 2000s, Korea failed to catch up with foreign PV industry mainly because of the malfunction of the financial mechanism, although it made efforts to create PV markets.

Firstly, I have explored the change of Korean political economy in order to identify institutional configuration of Korean economy. During the industrialisation process between the 1960s and 1980s, the state-bank-*chaebol* nexus had played a major role in the rapid economic development. Since the 1990s, however, liberalisation of the Korean economy has been geared towards the global trend. In the process of liberalisation, the 1997 crisis took place and the dismantling of the institutional instruments of developmental state and the advantages of diversification of *chaebols* accelerated mainly through the restructuring programmes.

Secondly, I have explained the change of policy regime and its impact on development of a local PV industry. Under the collaboration of the two coalitions, the feed-in tariff was adopted dramatically in 2002. Consequently, it was successful to create domestic demand for PV. However, the timing of the boom in the domestic PV market was not suitable for the main actors in the Korean economy. In fact, *chaebols* had little opportunity to find new businesses under the restructuring programme in the early 2000s. Thus, as *chaebols* responded to the market expansion late, so import penetration increased in the domestic market. Eventually, the feed-in tariff was changed to the Renewable Portfolio Standard and the Korean PV industry fell behind the other leading countries of Germany and China.

Lastly, I have attempted to draw the inter-relationship between institutional advantage and necessary functions for development of the PV industry. Korea had an institutional advantage in creating PV markets, but it had an institutional disadvantage in mobilising capital in a new sector, especially in the 2000s. Thus, unlike Germany, Korea failed to facilitate to develop the PV industry through introducing the feed-in tariff.

CHAPTER VIII

COMPARISON OF THE THREE CASES

1. INTRODUCTION

I have examined the evolution of the PV industry in the context of Germany, China, and Korea in the previous chapters. At the end of each chapter, I have attempted to analyse inter-relationships between institutional advantages and the four necessary functions within each case. In this chapter, I shall compare the three cases within the conceptual framework.

Thus, the aim of this chapter is to identify causal relationships between institutional advantages and necessary functions for the development of the PV industry, through the comparison of the national growth trajectories in the three countries. By doing so, I shall attempt to assess the necessity and relative significance of these functions in developing the PV industry. In particular, two questions are answered: one is whether market formation is a necessary condition and the other is whether capital mobilisation is a core function.

With regard to other two functions, I argue that they are also important to establish the PV industry. In terms of innovation, Germany took a lead by division of R&D, while China and Korea caught up with more advanced countries mainly by learning by manufacturing. In terms of cost reduction, each country utilised its own institutional advantage.

2. THE INTER-RELATIONSHIP BETWEEN INSTITUTIONAL ADVANTAGE AND NECESSARY FUNCTIONS

As I discuss the conceptual framework in chapter III, I shall examine in which countries institutional advantage plays a greater role in relation to the four necessary functions for the c-Si cell industry.

2.1 Market Formation: Demand-pull Policy

As Jacobbson and Bergek (2004) point out there is a long formative phase of the renewable energy sector, I assume that a market formation is one of the necessary conditions for establishing a PV industry. In particular, a demand-pull policy is essential to form a PV market because the electricity generated by PV systems is more expensive than those from other energy sources. In fact, the cost of PV electricity is five or ten times as high as that of conventional electricity, as shown in Table VIII-1. Thus, without government subsidies, PV energy cannot compete with other energy resources in the market. Therefore, a demand-pull policy such as the feed-in tariff can have a strong correlation with expansion of the PV market.

Table VIII-1 Costs of electricity production (unit: USD/MWh)

Energy source	USD/MWh
Wholesale power generation from conventional fuels	40-80
Wind (on shore)	70-140
Hydropower (large scale)	30-120
Biomass (solid fuels)	60-190
Geothermal (hydrothermal)	30-100
Tidal and marine currents	150-200
PV (low latitudes, Southern Europe, higher latitudes)	200-800 (200-400, 300-500, 500-800)

Source: 'Deploying Renewables' (IEA, 2008)

2.1.1 The Impact of Demand-pull Policies on PV Markets

In the 1980s, there were few demand-pull policies in the three countries. Thus, their demand for PV was very small, as shown in Table VIII-2.

Table VIII-2 Market demand for PV in the 1980s (unit: MWp)

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Germany				0.3	0	0	0	0	0.66	0
China								0.1	0.3	0.4
Korea	0.005	0.007	0.006	0.016	0.051	0.042	0.18	0.09	0.13	0.10

Source: KNREC, EPIA, CRED

In the 1990s, however, the demand for PV had increased as shown in Figure VIII-1 and Table VIII-3. Firstly, due to the 1,000 roof programme and local-level activities such as the Aachen model, the German PV market grew steadily and reached over 10 MWp in the late 1990s (V.3.2.3 p. 94). Secondly, even though a smaller increase to that of Germany, the demand for PV also increased in China, largely due to the electrification programmes and the international cooperation programmes (VI.3.2.3 p. 140). Thirdly, there remained little demand for PV in Korea because few programmes were implemented at that time. However, although the demand for PV increased in Germany and China, the amount was not sufficient to induce investment for mass production of PV.

Figure VIII-1 Market demand for PV in the 1990s (unit: MWp)

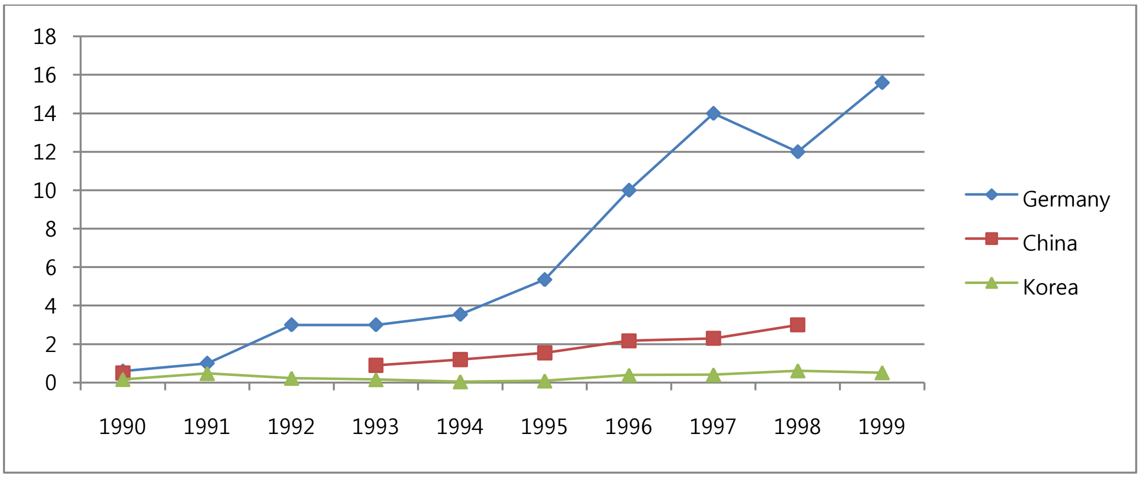


Table VIII-3 Market demand for PV in the 1990s (unit: MWp)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Germany	0.59	1.01	3.1	3.28	3.54	5.35	10.1	14	12.01	15.6
China	0.5	-	-	0.9	1.2	1.55	2.17	2.3	3	-
Korea	0.17	0.48	0.23	0.16	0.05	0.09	0.39	0.41	0.62	0.52

Source: KNREC, EPIA, CRED

The PV market did not take off until the 2000s. In the 2000s, a substantial growth in PV demand occurred in Germany, as shown in Figure VIII-2 and Table VIII-4. This enormous expansion of the PV market was mainly due to the revision of the feed-in tariff[108] in 2000. In addition, the 100,000 roof programme was implemented by the Red-Green coalition. In fact, the average annual growth rate of the market was around 100 per cent except in 2006. Similarly, the Korean government adopted the feed-in tariff from 2002, thus allowing the PV market to reach 276 MWp in 2008. However, the Korean PV market went down in 2009 because the market cap, which can be applied to the feed-in rate, was only 50 MWp in 2009. In contrast, the feed-in tariff had not yet been implemented in China[109], with only the rural electrification programme (*Song Dian Dao Xiang*) in place at this stage. Thus, the PV market was still behind in China.

Figure VIII-2 Market demand for PV in the 2000s (unit: MWp)

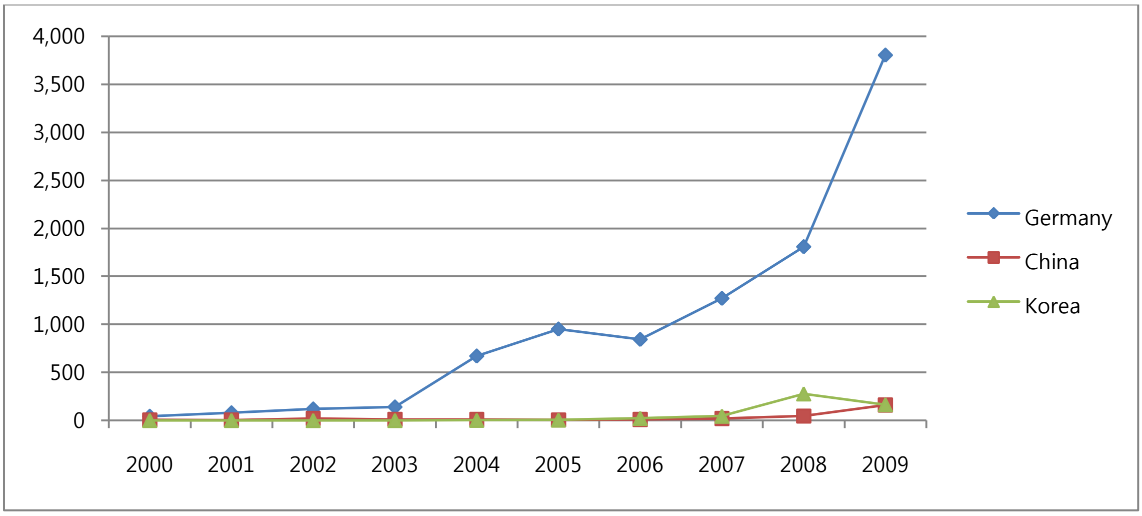


Table VIII-4 Market demand for PV in the 2000s (unit: MWp)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Germany	42	78	118	139	670	951	843	1,271	1,809	3,806
China	5	4	20	10	10	5	10	20	45	160
Korea	0.53	0.79	0.48	0.56	2.6	5	22	45	276	164

Source: KNREC, EPIA, CRED

[108] To be more exact, the change of feed-in rate for PV electricity was from 17 to 99 pfennig (approx. 50 Euro cents) in the Renewable Energy Source Law (see V.3.3.1).

[109] Although China enacted the 'Renewable Energy Law' similar to the German one in 2006, the feed-in tariff was not yet implemented (CREDP, 2008). Moreover, according to interviews, the feed-in tariff has been implemented in Jiangsu Province, but the scale is very limited.

2.1.2 Is Market Formation a Necessary Condition?

At a global level, it is clear that the PV industry cannot grow without the creation of PV markets. This is because a market is vital for an industry. From this perspective, PV market creation is a necessary condition for the PV industry. However, it is not clear what the relationship between the creation of a domestic PV market and the development of a domestic PV industry is at a national level. This thesis focuses on an analysis of the national level and thus I should answer this question more clearly.

In the German case, due to the creation of the domestic PV market, the domestic PV industry was able to grow fast in the 2000s. In this case, Germany created not only the local PV market but also the global PV market. However, mainly due to the growth of the German PV market, China's PV industry grew fast without sufficient local PV markets in the 2000s. In the Chinese case, it appears that the creation of domestic PV markets is not a necessary condition in the development of the domestic PV industry.

However, when we consider the characteristics of domestic PV markets in the formative period (Jacobsson and Bergek, 2004), the answer becomes more complicated. The PV market is different from normal trade goods' markets such as wine and clothes. Still, the PV market depends heavily on national policies such as the feed-in tariff. Adoption or abolition of the policy can affect, to a large extent, the success of the domestic PV industry, as discussed in the Korean case. If some countries which have major PV markets give up the feed-in tariff, other countries which have a large production capacity but without sufficient domestic PV markets can encounter difficulties. The best example of this is the Spanish case in which due to the shrinkage of the Spanish PV market in 2009, the Chinese PV industry found it difficult to survive.

When it comes to the current status of China's PV sector, it is easier to answer the question. In 2009, Chinese PV products accounted for around 40 per cent of world PV production, whilst the Chinese PV market accounted for around 2 per cent of the world PV market (EPIA, 2010; ECJRC, 2010). If the German PV market, which accounted for 53 per cent of the world PV market in 2009 (EPIA, 2010), shrinks, the Chinese PV industry will encounter more difficulties than in the Spanish case. If this takes place, the Chinese government may have to create domestic PV markets for its PV industry, as it established the Golden Sun project (500MWp) when the Spanish market fell (VI.3.3.8 p. 159). Thus, it is necessary for China to create a domestic PV market for the sustainable growth of its PV industry.

In short, although domestic market creation is not a necessary condition in the development of the PV industry, it is essential for its sustainable growth in China.

2.1.3 Sub-conclusions

In terms of market formation, it is clear that Germany has had an institutional advantage compared with China and Korea. Germany satisfied the necessary conditions for a 'change in gear' to take place. In other words, Germany successfully constructed a self-sustaining circular relationship between market formation, institutional change, entry of firms, and a formation of technology-specific advocacy coalitions (Jacobsson and Bergek, 2004). The feed-in tariff resulted in the growth of the PV market. The expansion of the PV market provided the PV industry with opportunities to grow. Moreover, the PV industry supported the feed-in tariff. This is the typical virtuous circle, expressed as a cumulative causation by Myrdal (1957, cited in Jacobsson and Bergek, 2004).

In contrast, China has had an extreme disadvantage in terms of market formation. Without sufficient domestic demand, the local PV industry was vulnerable to an exogenous impact. In fact, most Chinese PV firms had difficulty doing business after the financial crisis of 2008 because they were highly dependent on exports to the global market. Furthermore, there has been a tendency toward rising protectionism against PV trade such as 'Buy America'. This is another challenge for the Chinese PV industry because it does not have a sufficient portion of the domestic PV market.

In this respect, an institutional advantage became an institutional disadvantage in Korea. Until 2008, the Korean PV market expanded due to the feed-in tariff, but it shrank in 2009 mainly because of the abrupt change of the policy. Thus, the Korean PV industry was exposed to the same problems as China in terms of market formation. Furthermore, the Korean case reveals that market creation is not a sufficient condition for development of the PV industry. Although market creation took place in the Korean case, the domestic PV industry was not developed well due to the lack of other necessary conditions. This point will be discussed in the next sub-section.

2.2 Capital Mobilisation

In this sub-section, I will focus on the c-Si cell industry in the 2000s, as I mention earlier (III.4.2 and IV.1.2). During this period, c-Si cell technology was mature and a dominant design was established. Also at this time, production processes were standardised, thus making it the best strategy for firms to expand their production capacities as quickly as possible so that they could achieve economies of scale. In this sense, the ability to mobilise capital was the core competence for firms, because the industry was capital-intensive. In other words, rapid capital mobilisation was one of the necessary conditions for the industry. Normally, it is said that a 300 MWp of annual production capacity was the minimum efficient scale. This scale required at least 200 billion KW (approx. 200 million USD) of investment excluding the land costs.

2.2.1 Financial Markets versus Non-Market Mechanisms

From the viewpoint of investors who are interested in the c-Si cell industry, the period of the 2000s can be divided into two sub-periods: one is the period between 2000 and 2004; the other is between 2005 and 2009. It was said that the former period was an uncertain and risky time to invest in this industry, whereas the latter was an optimistic time to do so. Thus, I will examine the two periods separately.

2.2.1.1 Too Risky to Invest: between 2000 and 2004

Until 2004, normal investors thought of the PV industry as risky and uncertain, mainly because the PV market was not large enough to build a mass production facility. However, some entrepreneurs entered into this industry regardless of high risk. They were Q-Cells, SolarWorld, Sunways, Ersol in Germany; Suntech, Yingli, Trina Solar in

China; and Nesco Solar, Photon Semiconductor in Korea. Raising funds was their most challenging problem during this period. The German and Chinese firms appear to succeed in solving it, whereas the Korean firms seem to fail, as shown in Figure VIII-3 and Table VIII-5.

Figure VIII-3 Expansion of production capacity, 2000-2004 (unit: MWp)

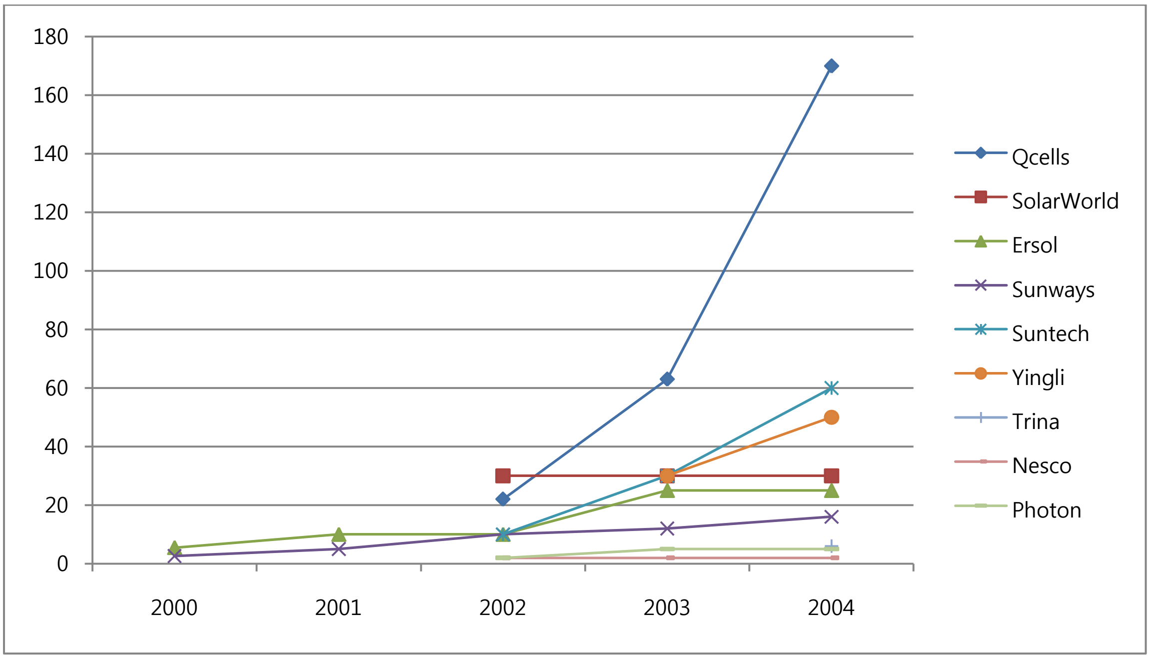


Table VIII-5 Expansion of production capacity, 2000-2004 (unit: MWp)

	company	2000	2001	2002	2003	2004
Germany	Q-Cells			22	63	170
	SolarWorld			30	30	30
	Ersol	5.5	10	10	25	25
	Sunways	2.6	5	10	12	16
China	Suntech			10	30	60
	Yingli				30	50
	Trina Solar					6
Korea	Nesco Solar			2	2	2
	Photon Semiconductor			2	5	5

Source: Firms' annual reports and web sites and interviews

These differences may be explained partly by their entrepreneurship or by their ability to convince investors. However, I will focus on the institutional differences between nations as the focus of this study is directed not at the firm-level but at the national level. More importantly, the financial institutional mechanisms were significantly different between the German case and the Chinese one.

In Germany, direct and indirect financial markets played a major role in expanding their production capacities. Stock markets, corporate bond markets and banks provided them with funds to invest. Mainly due to the well-developed financial markets, the German PV firms were able to raise funds to invest in their initial growths during this period.

Compared with the German case, differentiated mechanisms worked in capital mobilisation in China. In this period, the Chinese PV firms encountered more difficulties than the German ones, because they had neither sufficient domestic demand, nor did they export their products. For example, in 2003, they had more than a 60MWp production capacity (Table VIII-5 p.227), but the domestic demand was only 10 MWp (Table VIII-4 p. 223). Furthermore, at this time, the Chinese PV firms hardly exported their products because they had no credit in the global market. Thus, investment in the PV industry was highly risky in China during this period. However, they gradually invested mainly due to the so-called 'local state corporatism' (VI.3.3.3.1 p. 149). Chinese local governments had strong incentives to facilitate the growth of local industries because of the fiscal decentralisation and the evaluation system of cadres and high officials (Oi, 1999; Arrighi, 2007). In fact, city (*shi*) governments, banks, and local SOEs (State Owned Enterprises) provided them with funds to invest their initial production facilities.

In contrast, the Korean companies failed to increase their production capacities during this period. Due to the *chaebol*-dominant economic structure, SMEs (small-medium enterprises) had little access to financial markets such as bank loans and the stock market (VII.3.3.2.2.2 p. 208). Furthermore, venture capital markets had shrunk since the venture bubble burst in 2000 (VII.2.3.2 p. 178). Thus, they could not afford to raise funds to invest in the expansion of their production capacities.

2.2.1.2 Bright Enough to Invest: between 2005 and 2009

After 2004, investors' expectations of the PV industry totally changed. Mainly due to phenomenal growth in the European market, especially in the German market in 2004 (Figure VIII-2 and Table VIII-4 p. 223), they thought that the likelihood of future growth in the PV market was high. Not only the investors, but incumbent large firms of other sectors also believed this to be true. Thus, they rushed into the PV industry, as shown in Figure VIII-4 and Table VIII-6. They were Schott Group and Bosch Group in Germany; China Sunergy, JA Solar and Solarfun in China[110]; and Hyundai Heavy Industries (HHI), Samsung Electronics, LG Electronics, STX Group, and Hanwha Group[111] in Korea. Significantly, earlier entrants who had a readiness to grow expanded their production capacity at an unprecedented rate, such as Q-Cells and Suntech, as illustrated in Figure VIII-4. Finally, two firms in Germany and six firms in China went over a 300MWp capacity, the minimum efficient scale in the c-Si cell industry, at the end of 2009.

Figure VIII-4 Expansion of production capacity, 2005-2009 (unit: MWp)

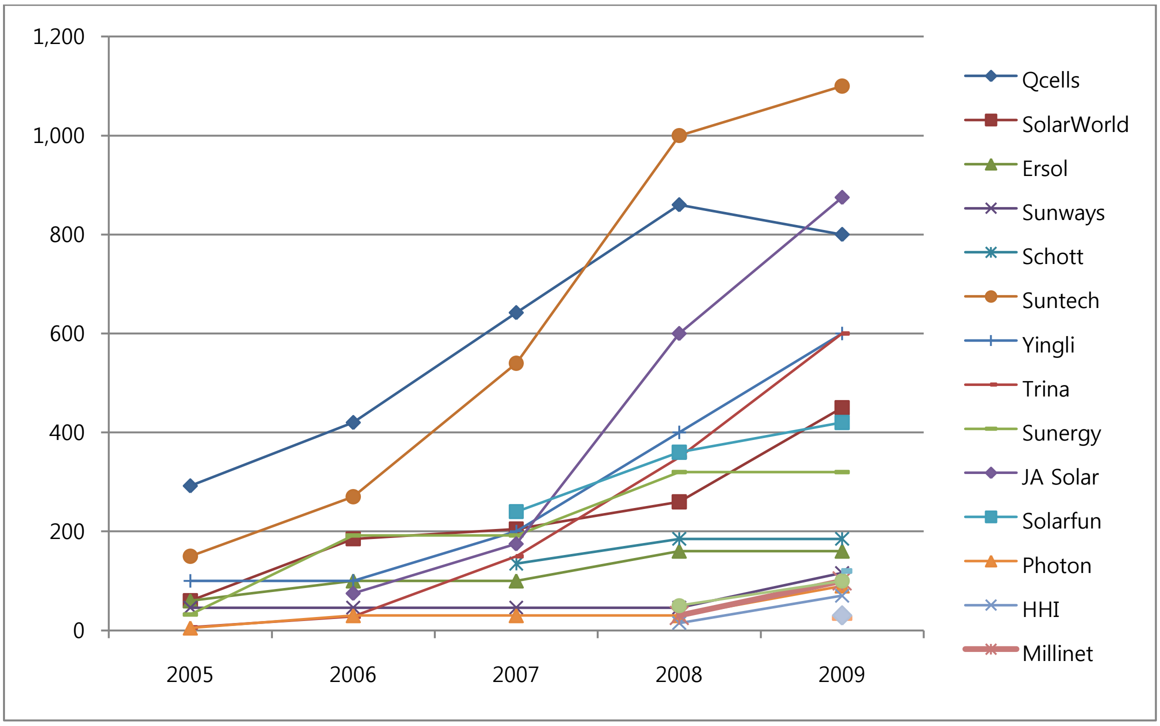


Table VIII-6 Expansion of production capacity, 2005-2009 (unit: MWp)

	company	2005	2006	2007	2008	2009
Germany	Q-Cells	292	420	642	860	800
	SolarWorld	60	185	205	260	450
	Ersol (Bosch Solar)	60	100	100	160	160
	Sunways	46	46	46	46	116
	Schott Solar			135	185	185
China	Suntech	150	270	540	1,000	1,100

[110] China Sunergy is a kind of subsidiary of CEEG (China Electric Equipment Group), JA Solar is a subsidiary of Jinglong Group (a wafer producer), and Solarfun is a subsidiary of Linyang Electronics (an electricity-measuring instrument manufacturer).

[111] All of them are *chaebols*.

	Yingli	100	100	200	400	600
	Trina Solar	6	28	150	350	600
	China Sunergy	32	192	192	320	320
	JA Solar		75	175	600	875
	Solarfun			240	360	420
Korea	Photon Semiconductor	5	30	30	30	90
	HHI				15	70
	Millinet				30	100
	Shinsung				50	100
	Samsung					30
	LG					120
	STX					25
	Hanhwa					30

Source: Firms' annual reports, web sites and interviews

Similarly to the first period, the national pattern of response to the market change differed from each other in terms of capital mobilisation. In Germany, PV firms utilised the financial markets, especially the stock market. For example, Ersol and Q-Cells raised about 153 and 240 million Euros respectively through their IPOs on the Frankfurt Stock Exchange in 2005. SolarWorld also raised about 234 million Euros through issuing new shares on the stock market in 2006.

From 2005, however, based on the local state corporatism, the Chinese PV firms had begun to tap into the US stock markets such as the New York Stock Exchange and Nasdaq. By 2007, all of the top 6 PV firms were listed on the foreign stock market (VI.3.3.3.2 p. 150). Global financing through foreign stock markets is another distinctive feature of the Chinese PV industry. Tapping overseas capital pools enabled them to expand their production capacities faster than any other country. Indeed, this new way of financing came into fashion not only in the PV sector but also in other sectors in China. Due to institutional changes which occurred after joining the WTO, Chinese firms were able to get access to foreign stock markets more easily than ever before. Therefore, the institutional change in the financial sector was an institutional advantage for the Chinese PV sector in terms of capital mobilisation.

In spite of this optimistic market change, Korean *chaebols* entered late into the PV industry. Mainly due to the Korean government's restructuring programmes in the financial and corporate sectors in the mid-2000s (VII.3.3.2.3 p. 211), *chaebols* seemed to have no room to invest in new sectors such as the PV industry. Although many

Korean institutes' reports pointed out the lack of alternative engines of future growth, they had no choice but to concentrate on their core sectors such as the semiconductor and shipbuilding industries.

2.2.2 Is Capital Mobilisation a Core Function?

In Germany and China, the PV industry was established in the 2000s, whereas this did not happen in Korea. Obviously, many factors have contributed to these differences. However, one factor was the most significant in creating these differences, that of capital mobilisation.

In fact, Germany and China succeeded in capital mobilisation in the PV sector in the 2000s, whilst Korea did not. In Germany, relatively well-developed financial markets provided the PV industry with capital. Furthermore, the PV industry benefitted from the incentive systems introduced after the unification in East Germany. In China, local state corporatism played a crucial role in providing the PV industry with capital, especially in the initial stage. In addition, the foreign stock market accelerated the speed of fund raising in the PV industry. In these two cases, local governments played an active role in promoting investment in its localities. However, the government support system was dismantled at this time in Korea and moreover, private actors could not afford to invest into the PV sector under the restructuring programmes.

Thus, I argue that capital mobilisation was the most important function in establishing the PV industry in the 2000s. Moreover, action taken by governments, in particular that of local governments, played a decisive role in facilitating this capital mobilisation. The three cases provide evidence that capital mobilisation was a core function in the development of the PV industry.

2.2.3 Sub-conclusions

Gerschenkron (1962) argues that differentiated institutional instruments contributed to the industrialisation of Britain, Germany and Russia in the nineteenth century. In terms of capital mobilisation, the investment banks and the state played a major role in Germany and Russia, respectively, unlike in Britain (Gerschenkron, 1962).

Similarly to Gerschenkron's[112] point of view, differentiated institutional advantages attributed to the rapid growth of the PV industry in Germany and China. Well-developed financial markets and incentive systems after the unification contributed to the German PV industry, whereas the local state corporatism and the institutional change which allowed improved access to foreign financial markets contributed to the Chinese PV industry. On the other hand, Korea had a crucial disadvantage in mobilising capital for the PV industry in the 2000s. Therefore, capital mobilisation was a core prerequisite for development of the c-Si cell industry in the 2000s, as in the iron and steel industry in Europe in the nineteenth century.

2.3 Process Innovation

In the 2000s, a dominant design was established in the c-Si cell industry. In addition, production processes were standardised in eight steps as described earlier (III.4.2.3 p. 54). Moreover, it is said that a production facility which is built on turn-key based imported equipment guarantees about 16% of conversion efficiency of cells. This means that cell manufacturers rely heavily on equipment suppliers as sources of innovation. In these circumstances, national systems of innovation responded differently, as I will explain in this sub-section.

2.3.1 National Systems of Innovation

There have been two main issues in the c-Si cell industry in terms of process innovation: one is how to make wafers thinner and the other is how to increase conversion

[112] However, there are some limitations in applying the Gerschenkronian three-country comparative schema to this comparative analysis. In terms of 'the degree of backwardness' (Gerschenkron, 1962), Korea can be regarded as a moderately backward country, while China as an extremely backward one. However, the comparative setting of this study is not entirely suited to Gerschenkron's three-country paradigm, because Korea had not caught up with the German PV industry at this point.

efficiency of cells. As shown in Table VIII-7 and Table VIII-8, improvements have been made in both fields, thus most of the major cell firms now use 180-200 μm of thickness wafers and produce 17-18 percent of conversion efficiency cells.

Table VIII-7 Decrease of wafer thickness (unit: μm)

	2003	2004	2005	2006	2007	2008
Q-Cells	330	275	230	200	180	
SolarWorld			240	210		180
Suntech						180
Millinet Solar						200
Shinsung						200

Source: Each firm's annual report

Table VIII-8 PV cell efficiency of the new generation of PV firms (unit: %)

		2002	2003	2004	2005	2006	2007	2008	2009
SolarWorld	Poly	14	15					18	
	Mono							20	
Q-Cells	Poly						17		
	Mono				20.5* (100cm²)				17.4
Sunways	Poly	14	15.7						16
	Mono		16.7						18.4
Suntech	Mono	14			15		16.5	17.8	19.2 (Pluto)
China Sunergy	Mono								17.5
Millinet Solar	Poly							15	16.2
Shinsung	Mono							16	17.4

Source: Each firm's annual report and press release

Poly: Poly crystalline silicon cells

Mono: Mono crystalline silicon cells

* a medium sized industrially applicable cell

However, the paths to reach the present status have been different. In Germany, close relationships between PV firms and equipment suppliers, and dense networks among firms, research institutes and universities enabled the German PV firms to lead technological innovation in the world PV sector. Firstly, the German equipment industry which was highly competitive in the world market, contributed to process innovation in the German PV industry. This was due to the fact that almost all the production processes of PV cells are automated by machinery. Secondly, the German PV firms have cooperated with renowned research institutes and universities in the research on PV technology such as Fraunhofer Society and Konstanz University. The strong partnership with world leading research institutes and universities is one of institutional advantages for the German PV industry. Lastly, they have cooperated with other PV companies to incorporate Joint Ventures (JVs) and participate in stock holding of other firms. These institutional advantages in the innovation of the German PV industry cover not only process innovation but also product innovation such as various thin-film technologies.

In contrast to the German case, the tradition of cooperation between firms and research institutes and universities has not been well established in China. Rather, the main paths to innovation were technological learning associated with advanced foreign countries: codified knowledge was learned mainly by import of state-of-the-art equipment and learning by manufacturing; tacit knowledge was introduced by Chinese returnee scientists and experienced engineers in the local PV firms. Although cooperation and collaborations between PV firms and universities have increased, they seem not yet to be the main factor in contributing to process innovation in the Chinese PV industry.

As in China, innovation in the Korean PV industry has relied heavily on imported equipment. However, the well-developed semiconductor equipment industry provides potential for development of a PV equipment industry in Korea, because they are close to each other in terms of production processes. For example, Shinsung, a medium-sized enterprise which originally produced semiconductor equipment, achieved 19.6 per cent of conversion efficiency of mono c-Si cells in November 2010. On the other hand, *chaebols* have strength in R&D through internal human resourcing. For example, Samsung Electronics and LG Electronics brought scientists and engineers who were involved with PV technology together into their PV business units.

2.3.2 Sub-conclusions

It is difficult to deny that Germany has an overwhelming institutional advantage compared to other countries in terms of innovation. It has a long tradition of strong cooperation among firms, research institutes and universities, and the PV sector is not an exception. Thus, the German PV industry can be regarded as a frontier in the world

PV sector, not only in its process innovation but also in its product innovation.

Compared with Germany, China has learned basic science and applied technology in the PV sector. In this respect, the Chinese PV industry is still a follower of more advanced countries. However, as far as c-Si cell manufacturing is concerned, the Chinese PV industry has a similar level of technological capability compared to that of Germany. Thus, they have caught up with the German PV industry not only in terms of production capacity but also in terms of process innovation.

Also, the Korean PV industry is still a follower. Like China, Korea has learned advanced technology from foreign countries and has relied on imported capital goods. However, in terms of innovation, Korea has an institutional advantage of so called ‘group-based coordination’, compared to ‘industry-based cooperation’ in the German case (Hall and Soskice, 2001, p. 34).

2.4 Cost Reduction[113]

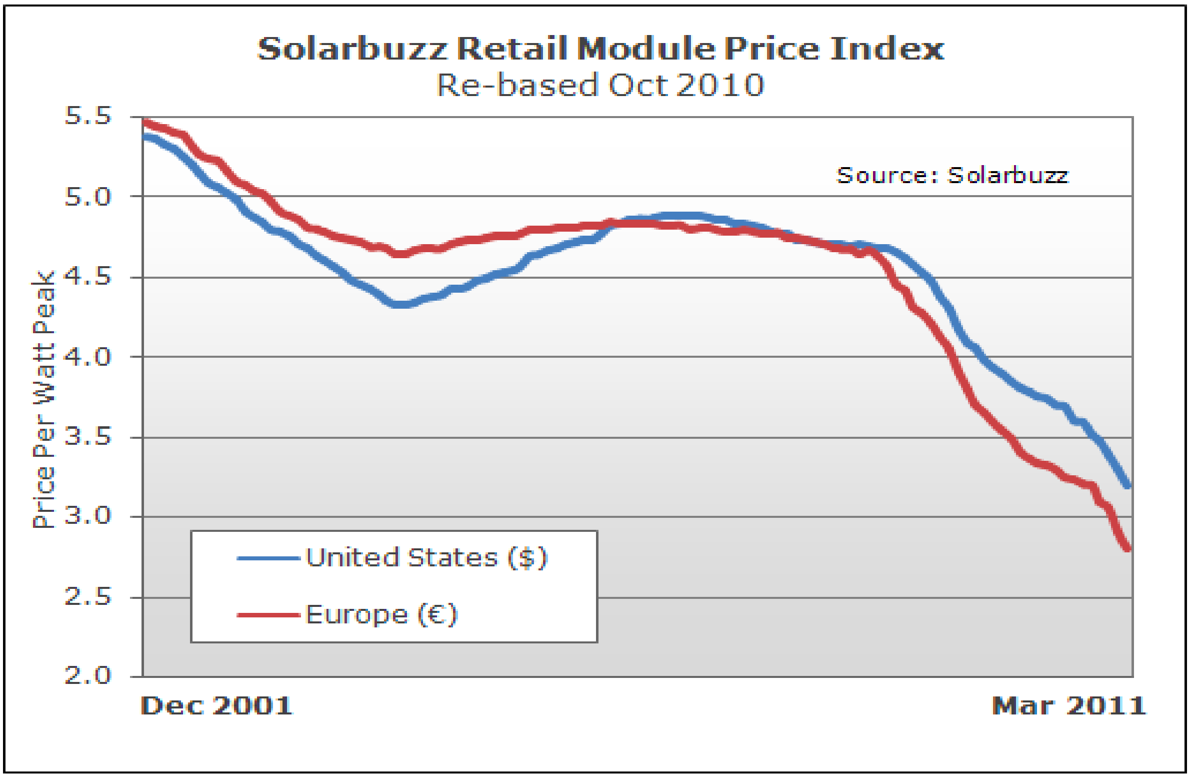
Process innovation is also related to cost reduction, however, other issues such as labour and land costs can be included in the concept of cost reduction. Thus, cost reduction excluding technological innovation will be examined in this sub-section, because it is very important for the PV industry in the context of global competition.

2.4.1 Price and Profitability

When it comes to trends of module prices, they have decreased rapidly since the late 2000s, as shown in Figure VIII-5. This is mainly due to two reasons: one is the falling price of poly silicon[114] and the other is severe competition among cell or module manufacturers.

[113] In this part, it is difficult to access cost information of the Korean PV firms, because most of them have started PV businesses since 2008. Thus, the Korean case is excluded in this sub-section.
[114] The spot price of poly silicon was around 400 USD/kg in 2008, but it dropped to about 50 USD/kg in 2009.

Figure VIII-5 Trends of module prices (unit: USD and Euro per Wp)



Source: Solarbuzz, 2011 (Available: http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices) [accessed 19th April 2011].

Due to the heavy global competition, the price of solar cells and modules of the German and Chinese PV firms also dropped in 2009, as shown in Table VIII-9 and Table VIII-10. In particular, the price of Chinese cells and modules fell further than that of the German ones.

Table VIII-9 Price of solar cells (unit: USD/Wp)

		2003	2004	2005	2006	2007	2008	2009
Germany	Q-Cells	1.99	2.11	2.24	2.68	3.03	3.22	**2.07**
	SolarWorld	2.14	2.16					
China	Suntech		2.02	3.05	3.23	3.06	2.84	**1.03**
	Solarfun			3.00	3.07	2.75		
	JA Solar				3.32	3.08	3.24	
	China Sunergy			3.10	3.22	3.17	3.27	**1.47**

Sources: Firms' annual reports

Table VIII-10 Price of solar modules (unit: USD/Wp)

		2003	2004	2005	2006	2007	2008	2009
Germany	SolarWorld	3.28						
China	Suntech		3.01	3.42	3.89	3.72	3.89	**2.40**
	Yingli		2.83	3.49	3.82	3.86	3.88	**2.00**
	Solarfun			3.93	3.99	3.74	3.92	
	Trina Solar		3.45	4.02	3.98	3.80	3.92	**2.10**

Sources: Firms' annual reports

Although the price of the Chinese ones went down more than that of the German ones, the profitability of the German firms worsened in comparison with the Chinese firms. With regard to the operating income margin, which shows profitability of firms, the German PV firms were slightly better than the Chinese PV firms until 2007 except Sunways, as listed in Table VIII-11. However, the profitability of the German PV firms has decreased since 2008, whereas that of the Chinese firms has remained largely the same. Given the further decrease in the price of Chinese cells and modules, compared to that of German ones, it is not difficult to infer that cost can be a major factor affecting profitability in the German PV firms[115]. In fact, due to higher costs than the Chinese firms, Q-Cells and Sunways recorded operating losses in 2009, as shown in Table VIII-11.

Table VIII-11 Operating income margin (OIM) of the German and Chinese PV firms

	firms		2002	2003	2004	2005	2006	2007	2008	2009
Germany (m. Euro)	Q-Cells	Revenue	17.3	48.8	129	299	540	859	1,251	802
		OI*	0.9	5.3	19.6	63.2	129	197	205	-486
		OIM** (%)	**5**	**11**	**15**	**21**	**24**	**23**	**16**	**-61**
	SolarWorld	Revenue	109	98.5	200	356	515	690	900	1,012
		OI	2.4	-3.1	32.9	88.6	178	199	263	152
		OIM (%)	**2.2**	**-3**	**16.5**	**24.8**	**34.9**	**28.8**	**29.2**	**15**
	Sunways	Revenue	27.5	38.7	66.9	90.9	152	214	262	178
		OI	-1.8	-2.1	3.1	2.1	1.0	4.1	-1.5	-0.5
		OIM (%)	**-6.5**	**-5.4**	**4.6**	**2.3**	**0.7**	**1.9**	**-0.6**	**-0.3**
China (m. USD)	Suntech	Revenue	3	14	85	226	599	1,348	1,924	1,693
		OI	-1	0.8	20	44	105	184	182	174
		OIM (%)	**-33**	**6**	**24**	**19**	**17**	**14**	**9**	**10**
	Yingli	Revenue		2.8	14.5	44	205	556	1,107	1,063
		OI		0.5	1.7	10	46	93	169	46.7
		OIM (%)		**17**	**11**	**23**	**22.4**	**16.7**	**15.3**	**4.4**
	Trina Solar	Revenue			0.4	27.3	115	302	832	845
		OI			-0.3	4.3	16.9	36	100	135
		OIM (%)			**-75**	**16**	**15**	**12**	**12**	**16**

Source: Firms' annual reports

[115] Profit = revenue – cost, thus the higher costs, the lower profits.

*OI (operating income) or EBIT (Earning Before Interest and Tax)

**OIM (Operating Income Margin) = operating income/revenue

2.4.2 Labour, R&D and Investment Costs

There are many costs associated with a firm's activities, but I will focus on three costs: labour costs; research and development costs; and investment costs, especially green field investment costs.

Firstly, low labour cost is the most important comparative advantage for labour abundant countries. Thus, China has an explicit cost advantage over other countries. In particular, because a module-manufacturing chain is more labour-intensive than other value chains, cheap labour seems to contribute to the competitiveness of the PV industry. In fact, personnel expenses per employee of the German PV firms was more than seven times as high as those of the Chinese ones in 2009, as listed in Table VIII-12.

Table VIII-12 Personnel expenses per employee (unit: Euro)

		2003	2004	2005	2006	2007	2008	2009
Germany	Q-Cells	21,831	20,756	28,385	32,940	29,584	29,322	33,022
	SolarWorld	35,501	50,054	49,776	42,871	50,474	49,386	49,892
	Sunways	42,667	44,444	34,390	40,575	42,558	39,623	47,950
China*	Suntech		2,735	11,078	6,833	6,117	6,435	4,409
	Yingli			1,910	2,966	5,445	5,553	7,425
	Trina Solar				5,029	3,730	6,075	5,963

Source: Firms' annual reports

*In the Chinese firms, the real personnel expenses[116] are smaller than these numbers, because I use general administration expenses as a proxy for personnel expenses (general administration expenses: salaries and benefits for administrative, finance and human resources personnel, depreciation of equipment used for administrative and amortization of rental facilities used for administrative purposes, provision for doubtful debts, fees and expenses of legal, accounting and other professional services, expenses associated with administrative offices).

Secondly, low R&D costs are another advantage of the Chinese PV industry. The traditional PV firms and many local universities have supplied the new generation of

[116] According to interviews, the salary of workers in PV factories was between 1,000 and 1,500 RMB (approx. 146 and 220 USD) a month in 2009 (In 2009, the official RMB/USD exchange rate was around 6.83).

PV firms with skilled human resources, such as technicians and engineers. Thus, quality control on production processes and in-house R&D were more affordable in China than in Germany. For example, considering the large number of science and engineering degrees achieved[117] in China, it is unlikely to be an exaggeration that their initial salaries are in the region of 3,000 RMB (approx. 440 USD) a month.

Lastly, with regard to investment costs, the German PV industry has been one of the beneficiaries of regional clustering policies such as 'SolarValley Central Germany (*Solarvalley Mitteldeustchland*)', while the Chinese PV industry has been offered preferential treatment by local governments. For example, *Solarvalley Mitteldeustchland* provided firms' investments in *Thüringen*, *Sachsen*, and *Sachsen-Anhalt* with investment grants which are allowed up to 30 to 50 per cent of eligible investment costs, while Chinese local governments offered preferential land uses or taxation for local PV firms.

2.4.3 Sub-conclusions

In terms of cost reduction, China has explicit cost advantages compared with Germany. Labour and R&D costs in China are substantially lower than those of Germany, even though there seem not to be significant differences in quality between them. Under severe global price competition, cost disadvantages of the German PV firms resulted in operational loss in 2009.

Unlike labour and R&D cost advantages, investment cost advantage heavily relies on the supportive institutions such as *Solarvalley Mitteldeustchland* in Germany and local state corporatism in China.

[117] In 2002, more than 300,000 scientists and engineers graduated from universities in China (Marigo, 2009, p. 180)

3. CONCLUDING REMARKS

This chapter has compared the three cases in terms of four necessary conditions. In terms of market formation, Germany has an overwhelming advantage compared with China and Korea. In terms of capital mobilisation, each case has its own institutional advantages: a well-developed financial market and incentive systems after the unification in Germany; local state corporatism and global financing in China; and internal financing of *chaebols* in Korea. In terms of innovation, Germany has an institutional advantage both in process innovation and in product innovation, while China and Korea are in the process of catching-up with more advanced countries. In terms of cost reduction, China has an explicit advantage over Germany and Korea.

In particular, as far as the three cases are concerned, market creation was not a generally necessary condition for the development of the PV industry. In Germany, the growth of domestic PV markets led to the development of the PV industry, whereas the PV industry grew without a sufficient domestic PV market in China. Thus, it does not necessarily follow that a creation domestic market is a necessary condition for the establishment of a local PV industry. However, market creation is still important because the PV industry cannot survive without it, especially at a global level. This point will be examined in the implications for China in the conclusion chapter (IX.3.2 p. 247).

With regard to capital mobilisation, Germany and China's mechanisms have worked well and they have succeeded in establishing the PV industry, whilst Korea failed to do mainly due to the malfunction of its financial mechanisms. Thus, it can be said that capital mobilisation played a crucial role in development of the c-Si cell industry in the 2000s. Indeed, defects in market formation of the PV industry can be resolved by exports, such as in the Chinese case, and process innovation can be achieved by technology transfer, such as the Chinese and Korean cases. However, capital mobilisation seems to be difficult to deal with, without establishing appropriate institutional mechanisms, as described in the Korean case. Therefore, I argue that capital mobilisation was the core necessary condition for the development of the c-Si cell industry in the 2000s.

CHAPTER IX CONCLUSIONS

This last chapter aims to clarify the arguments and key findings throughout this thesis and to outline the contributions, implications and limitations of this thesis. In section 1, I shall summarise the theoretical arguments and key findings. In section 2, the theoretical and empirical contributions of this study will be identified. In section 3, I shall attempt to draw implications for the three countries concerning future development of the PV industry. In the last section, I shall point out the limitations of this thesis and make suggestions for further research.

1. KEY FINDINGS

1.1 Theoretical Arguments

This study began with this research question: what are the main factors underlying the differences between national PV growth trajectories? In order to answer this question, two concepts have been explored: institutional advantage and necessary functions for the PV industry.

Firstly, I have argued that a certain type of institutional configuration in a nation is more conducive to the development of the PV industry than any other. Moreover, these institutional advantages are not general to all industries in any period but specific to a certain industry in a particular period.

Secondly, it has been assumed that four functions are required to facilitate the emergence and growth of the PV industry: market formation; capital mobilisation; process innovation; and cost reduction. These four functions are asserted as being necessary conditions for the development of the PV industry.

Therefore, a basic argument of this study under the theoretical framework is as follows:

If a country has institutional advantages which are relevant to the four functions, this country's PV industry will be developed faster than any other country.

In order to investigate the validity of this theoretical argument, empirical studies have been carried out.

1.2 Empirical Findings

Germany, China and Korea were selected for a comparative case study, because these countries showed contrasting results in terms of their relationship between market formation and industrial dynamics. Through the comparative analysis of these three cases, the following empirical findings have been deduced.

Firstly, market creation is not a generally necessary condition for the development of a PV industry. More specifically, domestic market creation is not a generally necessary condition for the development of a local PV industry at a national level. In other words, a local PV industry can be developed without sufficient domestic markets. The Chinese case exemplifies this finding. However, domestic market creation is important, because the domestic PV industry, national support policy and the domestic market are interrelated. If some countries which have major PV markets give up the national support policy, other countries which have a large production capacity without sufficient domestic PV markets can encounter difficulties. Thus, for China, domestic market creation is now required to attain sustainable growth of its PV industry.

Secondly, capital mobilisation is a core function in establishing the PV industry. In the 2000s, Korea failed to establish its local PV industry despite an institutional advantage in creating domestic markets, mainly due to the fact that it had an institutional disadvantage in mobilising capital. However, Germany and China succeeded in mobilising capital in their PV sectors, governments playing a decisive role in facilitating PV firms in raising funds in both cases. Without this institutional advantage in mobilising capital, it would have been difficult for the PV industry to emerge and evolve in Germany and China.

Thirdly, national systems of innovation of the three countries responded differently to process innovation which was required for the development of the PV industry. Due to the competitive equipment industry and the well-organised division of R&D between PV firms, research institutes and universities, Germany took a lead in technological innovation, not only in process innovation but also in product innovation. China and Korea learned and built technological capabilities through their own systems of innovation in order to catch up with more advanced countries. In particular, returning scientists and experienced engineers played a critical part in encouraging learning by manufacturing in China, while incumbent semiconductor and display industries provided the PV industry with complementary assets (Teece, 1986) and *chaebols* took advantage of internal human resourcing in Korea.

Lastly, cost reduction became more and more important, as the PV industry reached the mature stage within the ILC. Germany achieved cost reduction mainly by technological development, whereas China fully utilised its cost advantages such as lower-cost labour, lower-cost R&D and lower-cost investment.

2. CONTRIBUTIONS TO KNOWLEDGE

2.1 Theoretical Contributions

In the literature review chapter (II), I explored national level approaches, industrial dynamics approaches and linking concepts between the two levels. This has provided valuable insights in understanding different industrial dynamics across nations.

According to the VoC approach (Hall and Soskice, 2001), different PV national growth trajectories could be generated by different national institutional frameworks because firms are embedded in a nation-specific institutional structure. These national institutional instruments can be created through specific institutional responses (Gershchenkron, 1962; Shin, 1996). However, these institutional structures are differentiated systems in different nations and in different times (Gershenkron, 1962; Shin, 1996). The developmental state in Korea between the 1960s and 1970s (Amsden, 1989; Pirie, 2008) and the local state corporatism in China between the 1980s and 1990s (Oi, 1999) are the best examples to illustrate these particular institutional instruments.

From the perspective that regards an industry as a social system, it is argued that different subsystems of a new industry specialise in three functions: 'technical instrumental functions, resource procurement functions, and institutional legitimation and governance' (Van de Ven and Garud, 1989, p. 206). In addition, it is argued that characteristics of the formative period of renewable energy industries are identified as follows: 'market formation, the entry of firms and other organizations, institutional change and the formation of technology-specific advocacy coalitions' (Jacobsson and Bergek, 2004, p. 819). Germany's wind and PV sectors were examined using this framework of four features (Jacobsson and Lauber, 2006).

However, existing literature is limited in providing this research with an adequate tool to analyse comparatively the difference between the PV national growth trajectories. Linking national political economies and industrial dynamics, I have attempted to devise a comparative framework utilising the concept of 'comparative institutional advantage' (Hall and Soskice, 2001) and functions for the emergence of a new industry

(Van de Ven and Garud, 1989). Thus, I have proposed a conceptual framework in comparative analysis on the PV industry in the 2000s consisting of these four elements: institutional advantages relating to market formation, capital mobilisation, process innovation and cost reduction.

Thus, it can be said that this study contributes to a better understanding of the nature of industrial dynamics in the context of institutional configurations of a national political economy. In particular, the concept of 'institutional advantage' has been applied to comparative analysis on the emergence and evolution of the PV industry. Moreover, from the perspective of the social system, four necessary functions for the development of the PV industry have been proposed and investigated through the three cases. This new tool used to analyse the emergence of the PV industry can be equally applied in the analysis of industrial dynamics of other industries, especially renewable energy industries such as the wind energy industry.

2.2 Empirical Contributions

This research contributes to empirical knowledge in two ways: one is a further understanding of the development of the PV industry within each case; the other is a comparative understanding between the three cases. Comparative empirical findings are examined in sub-section IX.1.2, and given special attention original empirical findings in each case in this sub-section .

Firstly, many written texts have been utilised to examine the development of Germany's PV sector (Wolf, 1972; Smits, 1976; Palz, 1978; Palz, 1982; KPMG, 1999; Jacobbson *et als.*, 2004; Lauber and Mez, 2004; Jacobsson and Lauber, 2006; Wüstenhagen and Bilharz, 2006). In addition to using this literature, this research has explored the impact of German unification on the development of the PV industry. Due to the subsidy programmes implemented to support the economic development of East Germany, it has been easier than ever for German PV firms to mobilise capital.

Secondly, with regard to the Chinese PV industry, Marigo's (2009) PhD thesis was the first in-depth research to highlight, at firm-level, technological capability and a nation-level innovation system. However, her research mainly focused on technological issues, and only covered the time up until 2005. Going beyond her work, this research has examined not only technological issues but also the institutional framework of China's political economy and has covered the whole of the 2000s. Indeed, it is important to cover the second half of the 2000s for the research about China's PV industry, because China's PV industry surpassed more advanced countries during this period. Thus, this research has explained how China's PV industry has become the largest PV manufacturer in the world in aspects of capital mobilisation, technological caching-up and cost reduction.

Lastly, this research is the first in-depth investigation into the Korean PV industry. There have been many reports about PV support policy and the PV industry in Korea, but these reports are fragmented and not comprehensive in their understanding of the development of the PV industry in Korea. In particular, this research has revealed why Korea's PV industry did not grow fast despite the feed-in tariff and how the feed-in tariff was adopted and changed.

3. IMPLICATIONS FOR THE THREE COUNTRIES

3.1 Germany

According to Vernon's (1966) product cycle theory, the more a product is standardised, the greater the possibility that the industry will relocate to developing countries (see II.3.2.1 p. 32). It can be noted that the German PV industry fits this argument in that c-Si cells and modules are highly standardised. In fact, Q-Cells and Schott Solar moved their production facilities to Malaysia and the Czech Republic, respectively, in order to reduce production costs.

By moving its production facilities into lower cost areas, the German PV industry should be able to build a global value chain based on its institutional advantage of innovation. Moreover, Germany should consider how to retain its institutional advantage in product innovation and how to keep the equipment industry competitive, thus allowing the PV industry to maintain its advantage in developing new PV products and using state-of-the-art equipment.

Furthermore, Germany needs to maintain its institutional advantage in market formation until it achieves grid parity. The German PV industry has benefitted most from the feed-in tariff, because it enjoys the largest PV market in the world. Thus, it is important that the feed-in tariff is kept until it attains grid parity so that the German PV industry can enter the take-off phase, which Van de Ven and Garud (2000) define as the final stage of an ILC (see II.3.2.3 p. 34).

3.2 China

Considering current trends of rising labour costs in China, no one knows how long China's cost advantage will continue. Furthermore, local state corporatism, which has been a unique institutional advantage in the process of industrialisation in China, has to meet the challenge of complying with the rules of the WTO. Therefore, China needs to realise that its current institutional advantages are vulnerable and attempt to alter its institutional disadvantages.

Firstly, the findings of this study suggest that China should adopt a strong demand-pull policy, such as the feed-in tariff, so that the Chinese PV industry can be independent of fluctuations in world PV demand. Although the Renewable Energy Law was enacted in 2006 and Jiangsu Province started its feed-in tariff in 2009, the scale is very limited and a German-like, feed-in tariff has not yet been implemented in China. Thus, it is necessary for China to introduce this type of feed-in tariff not only to ensure stable growth of the Chinese PV industry, but also to avoid trade disputes with foreign organisations such as the US Steel Unions.

Secondly, it is essential to build a technological capability in order to establish a self-sustaining PV industry structure in terms of innovation. Although China's technological capability for process innovation in the c-Si cell industry is equal to more advanced countries, it is doubtful that this remains the case where thin film technology is concerned. In fact, in recent years[118], CdTe technology, one of the thin film technologies, has developed faster in more advanced countries. If PV technology is taken to include not only c-Si technology but also thin film technology, product innovation becomes crucial for the growth of the PV industry because thin film technology is not mature in terms of the ILC theory (Utterback, 1994). Therefore, it is necessary for China to strengthen the infrastructure of indigenous innovation: promoting basic science in local universities and research institutes; facilitating collaboration between firms, universities and research institutes; and providing incentives for overseas Chinese scientists to return.

3.3 Korea

In respect of market formation, Korea's PV industry experienced a cold-turkey type policy change from the feed-in tariff to RPS (see VII.3.3.1.4 p. 203). Due to this change, the domestic PV market shrank rapidly in 2009, as shown in Figure VII-6 and Table VII-7 (p. 200). If domestic PV markets increase sufficiently, a local PV industry will

[118] The market share of CdTe thin film in the world PV market rose from 2 to 13 per cent between 2005 and 2010 (Greenpeace and EPIA, 2011)

have more beneficial circumstances in which to grow, as shown in the German case. Thus, it is necessary for Korea to construct a mechanism to pull demands for PV into the RPS scheme, such as by implementing a quota system for PV electricity.

A more serious problem relates to capital mobilisation, not only in the PV sector, but also in other sectors in Korea's economy. Industrial policy has changed since the 1990s, as liberalisation of the political economy has continued and 'policy loans' are no longer made. However, financial markets for new industries were not well developed in comparison to those in more advanced economies such as Germany. For example, the role of banks was different from that of investment banks in Germany. Furthermore, a venture capital system was not properly established because of the collapse of the venture boom in the early 2000s. Thus, there remains only one actor who can afford to mobilise capital in the Korean economy, the *chaebol*. Given the *chaebol*-dominant industrial structure, if *chaebols* are not interested in a certain sector, the sector is unlikely to emerge and grow in Korea. In fact, a c-Si cell industry did not emerge until *chaebols* entered the industry. Therefore, it is necessary for Korea to build a financial system which can be accessed by small and medium-sized enterprises (SMEs) in order to overcome institutional disadvantage in terms of capital mobilisation.

With regard to innovation, it should be noted that Korea has experienced great success in the semiconductor and display sectors. Because of similar production processes between semiconductor and silicon solar cells and between display and thin film modules, Korea seems to have a technical advantage in developing the PV industry. However, it is necessary to overcome some technical differences between semiconductors and silicon solar cells and between display and thin film modules. This is illustrated by the fact that Siltron was a wafer manufacturer for semiconductors but failed to produce wafers for solar cells in the 1990s (see VII.3.2.3.2 p. 192).

4. LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

This research has adopted the case study as a research method. However, it can be said that case studies provide little basis for generalisation or theorising (Yin, 2009). Thus, this research may be limited in its ability to generalise its theoretical and empirical findings. However, it has not been the aim of this research to identify universal prerequisites for the development of the PV industry through generalisation. Rather, this research has been carried out to understand adequate causal relationships between institutional advantages and the national PV trajectories, as I discuss earlier (III.2 p. 42). In fact, this research provides in-depth insights into the understanding of the nature of industrial dynamics in the context of institutional configurations.

Although these insights emanate from the case study on the PV sector, it is valid to expand the case study to other sectors such as the wind energy industry in order to extend the applicability of the conceptual framework. Through examining other sectors, more general arguments about industrial dynamics can be inferred.

Theoretically, this research has focused more on the national and industrial level approaches rather than the firm or global level approaches. However, it appears that a relationship between global and national levels in particular attracts more attention from scholars who are interested in domestic institutional changes under globalisation (Weiss, 2003; Morgan, 2005; Whitley, 2005; Hancké et al., 2007; Pirie, 2008; Streeck, 2009). These include recent works which deal with the globalisation-national governance debate, and discuss whether current and differing capitalist models converge to neo-liberal capitalism under global competition.

Although this research has also examined the changes of domestic institutional configurations under increasing economic openness in Germany, China and Korea, this issue has not been a main focus of this study. Thus, if further research is carried out in terms of the relationship between globalisation and national governance, it will contribute to this debate.

Lastly, this research has revealed that domestic PV market creation has largely subsidised the development of other countries' PV industry. The relationship between Germany's feed-in tariff and China's PV industry is an example of this. That is to say, national PV support policy has externalities in terms of economics. In order to internalise these externalities, it is necessary to establish an international cooperation mechanism. Also this mechanism would be helpful for the planet to cope with global warming, because deploying renewable energy is one of the ways to cut could CO_2 emission, as I mention at the start of this thesis (I.1 p. 1). Thus, how to organise international cooperation around the feed-in tariff could be another topic of further research and could contribute to practical concerns as well as academic knowledge.

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Appendix 1 Interview Questions

I. Basic Information

1. The year of establishment
2. The number of employees and their salaries
   - The number of R&D personnel (scientists and engineers)
3. Annual sales/ Earnings Before Interest and Tax
4. The ratio of export
5. The record of wafer thickness and cell efficiency

II. Establishment and initial period

6. Who were the founders?
   - What were their careers (majors, degrees, former experience, etc.)?
   - What were their motives to found?
   - What were the circumstances when founding?

7. How did finance in expansion during initial period?
   - Banks, stock markets, or self-financing?
   - What was the role of governments in financing?

8. What were the main difficulties during initial period?
   - How did you overcome the difficulties?

III. Expansion of production capacity

9. How did you expand your production capacity?
   - Why did you expand rapidly?
   - How did you finance in each expansion?
   - What was the role of governments in financing?
   - Who were the main equipment suppliers in expansion?
   - How did you cut the expansion costs?

IV. Vertical integration

10. Who were suppliers and users in the value chain?
    - Why did you forward or backward integrate in the value chain?

V. Innovation

11. Have you collaborated with universities/research institutes/other firms?
    - What were the relationships with them in R&D?
    - What were the main goals in technological development?

VI. Government support

12. What were the main support from the central government and local governments?
    - Was the feed-in tariff helpful to your business?
    - What were the incentives to invest?

VII. Further Questions

13. What is the strength of your company? (China, Germany, Korea)
14. How did you start to export? (China)
15. How many engineers came from the traditional PV firms? (China)
16. Who did a major role in listing on the foreign stock market? (China)
17. Was the Jiangsu Province feed-in tariff helpful to your business? (China)
18. Was the Solarvalley Mitteldeutschland helpful to your business? (Germany)
19. What were difficulties when Chinese firms grew? (Germany)
20. Why were you late to enter the PV business? (Korea)

Appendix 2 Interviewees

I. Korea

	name	careers	date	place (or method)
firm	Bae, Sang Soon	A senior manager of Hanwha Chemical and a former CEO of Nesco Solar	20th December 2009 and 7th May 2010	Email and telephone
	Kim, Dong Sup	A director of Samsung Electronics	14th April 2010	Email and telephone
	Jung, Jee Won	A director of LG Electronics and a former senior researcher of LG Chemical	14th January 2010	Telephone
	Oh, Byung Doo	A former manager of LG Electronics and LG Chemical	4th January 2010	Telephone
	Park, Won Kyu	a former researcher of the Goldstar Central Institute (a participant of the National Project)	13th January 2010	Telephone
	Lee, Woo Hyun	A vice CEO of OCI (a poly-silicon manufacturer)	29th January 2010	Email
	Kim, Ki Hong	A managing director of OCI (a poly-silicon manufacturer)	1st February 2010	Email
	Han, Sung Ryong	A team manager of S-Energy (a module manufacturer)	15th March 2010	Telephone
	Kim, Woo Yeol	A managing director of KISCO (a thin-film manufacturer) and a former managing director of LG Electronics	18th March 2010	Telephone
	Shin, Dong Woo	A general manager of Millinet Solar	23rd March 2010	Email
	Cho, An Je	A former researcher of Lucky Materials and Siltron (a participant of the National Project)	16th April 2010	Telephone
	Lee, Won Jin	A manager of solar business team, Hyundai Heavy Industries	19th April 2010	Telephone and email
	Lee, Pak Il	a former CEO of KPE	27th April 2010	Email
	Kim, Jae Yoon	A team manager of Shinsung Holdings	29th April 2010	Telephone
	Lee, Tae Woo	A team manager of KPE	7th May 2010	Email

	Lee, Jun Sin	a founder of Photon Semiconductor and a professor in Sungkyunkwan University	28th June 2010	Telephone
Policy maker	Kim, Yong Tae	A deputy director, division of Energy technology, Ministry of Commerce, Industry and Energy	25th May 2009	Munich, Germany
	Kim, Bum Soo	a deputy director, division of the new & renewable energy, Ministry of Commerce, Industry and Energy	23rd September 2009	Email
	Kim, Kang Won	A team manager of Korea New and Renewable Energy Centre	23rd September 2009, 21st October 2009, etc.	Email
	Lee, Jae Hong	a former assistant director, division of Energy Technology, Ministry of Commerce, Industry and Energy (a introducer of the Feed-in tariff)	29th December 2009	Email
	Kim, Ki Joon	A director, division of new and renewable energy, Ministry of Commerce, Industry, and Energy	16th January 2010	Paris, France
	Oh, Il Young	A assistant director, division of environment technology, Ministry of Environment	22nd February 2010	Telephone
Expert	Kim, Sung Soo	a PhD researcher of Imperial College London and an assistant director of Education, Science and Technology of Ministry of Korea	30th November 2009 and 22nd December 2009	London (Imperial college) and telephone
	Yoon, Kyung Hoon	a Principal Researcher of New and Renewable Energy Research Division, Korea Institute of Energy Research in Republic of Korea	11th December 2009	Telephone
	Kim, Kang Won	A team manager of Korea New and Renewable Energy Centre	23rd September 2009, 21st October 2009, etc.	Email

II. China

	name	careers	date	place (or method)
firm	Xu, Honghua	A vice director, Institute of Electrical Engineering, Chinese Academy of Science and a former independent director of JA Solar	6th July 2010	Beijing
	Lee, Seok Jin	A vice president of sales & marketing in LDK Solar and a former Chief Operating Officer in Yingli	7th July 2010	Suzhou, Jiangsu Province
	Chen, Harry	A director of group office, Suntech	16th July 2010	Wuxi, Jiangsu Province
	Zhu, Jun	A manager of domestic market, Solarfun	19th July 2010	Qidong, Jiangsu Province
	Sun, Renbao	A vice manager of development & coordination department, China Sunergy	20th July 2010	Nanjing, Jiangsu Province
	Yang, Colin and Young, Thomas	A vice president of public affairs, Trina Solar A director of investor relations, Trina Solar	21st July 2010	Changzhou, Jiangsu Province
	Xia, Collin	A sales engineer, Shanghai Topsolar	22nd July 2010	Shanghai
	Cui, Ri	A sales manager of sales department, Suntech	27th July 2010	Wuxi, Jiangsu Province
Policy maker	Shao, Liqin	A vice director of National Strategy Consulting Committee for advanced material industry and a professor in Tsinghua University	2nd July 2010	Beijing
Expert	Ma, Lingjuan	A director assistant and deputy managing director of Chinese Renewable Energy Industries Association	5th July 2010	Beijing
	Li, Zhu	A senior associate of IT Group (a consulting firm)	25th June 2010	Telephone
	Wei, Qidong	a secretary general of Jiangsu PV Industry Association, a professor of Dongnan University	8th July 2010	Nanjing, Jiangsu Province
	Tang, Hong	A director of industrial park development department, Shanghai New Energy Industry Association	15th July 2010	Shanghai
	Wang, Wenjing	A professor, Institute of Electrical Engineering, Chinese Academy of Science	2nd August 2010	Telephone

III. Germany

	name	careers	date	place (or method)
firm	Ettrich, Klaus and Lawerenz, Alexander	A director of business unit solar, Forschungsinstitut für Microsensorik und Photovoltaik GmbH A head of photovoltaics department, Forschungsinstitut für Microsensorik und Photovoltaik GmbH	18th May 2011	Erfurt, Thuringia
	Peschke, Matthias	A Chief Operating Officer, Masdar PV GmbH	19th May 2011	Ichtershausen, Thuringia
	Woditsch, Peter	A former CEO of Deutsche Solar AG (current SolarWorld AG)	10th May 2011	Email
Policy maker	Schäfer, Barbara	Division KI III 5, research and development in the field of renewable energies, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	21st May 2011	Berlin
Expert	Chrometzka, Thomas	A head of international affairs, German Solar Industry Association (BSW)	16th May 2011	Berlin
	Seifert, Gerhard	A professor, Solarvalley Graduate School and Martin-Luther University	17th May 2011	Halle, Saxony-Anhalt
	Stütz, Herbert	A director of investment promotion Asia-Pacific region, LEG Thuringia	18th May 2011	Erfurt, Thuringia
	Bagdahn, Jörg	A director, Fraunhofer Center for Silicon Photovoltaics CSP	19th May 2011	Halle, Saxony-Anhalt